THE UNIVERSITY OF CALGARY

VISUAL ACCOMODATION AND MULTIPLE SCLEROSIS

by

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Abstract

Since accommodation exhibits substantial low frequency drifts, visual resolution also fluctuates correspondingly. Previous research (Raymond, 1986) has shown that viewing small stimuli at distances nearer to or farther away from that corresponding to the resting position of accommodation demands sustained accommodative effort in order to maintain stimulus resolution. The accommodative system is most efficient when viewing distance corresponds to the individual accommodative resting position and efficiency decreases substantially as the difference between resting position and optical distance is increased. The ability to sustain detection of a small letter stimulus was measured in a group of multiple sclerosis (MS) patients and age-matched controls. Since MS is associated with abnormal fatigue with prolonged exertion, episodes of blurring, reduced contrast sensitivity and other visual signs in MS patients may be accounted for by transient accommodative fatigue. Stimuli were presented in a Badal optical system so that accommodative distance could be changed without changing image size or brightness. A control experiment in which the lens was cyclopleged was conducted to separate accommodation and neural adaptation (e.g. Troxler fading) effects on stimulus resolution. Results indicate that accommodative function for near viewing distances is significantly attenuated in MS patients than in age-matched controls ($p<.05$). These results will be useful in assessing the extent to which dioptric factors contribute to the perceptual deficits experienced by MS patients.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

Visual Accommodation and Multiple Sclerosis

The purpose of this research was to investigate abnormal visual accommodative control in multiple sclerosis (MS) and its contribution to visual perceptual deficits. A large majority of MS patients, with normal to near-normal visual acuity, report episodes of transient blurred vision at some time during the course of the disease. This indicates that there may be neural and/or optical deficits affecting visual perception. It is hypothesized that an impaired ability to sustain detection, due in part to transient accommodative fatigue, may account for these puzzling visual deficits. Raymond (1986) indicates that it is effortful to exert and maintain accommodative control during prolonged viewing. Moreover, abnormal fatigue during prolonged exertion is a prevalent characteristic of MS. It was further expected that, based on modern concepts of accommodative control, MS patients would have impaired accommodative capacities to sustain accommodation to distances other than that corresponding to an accommodative tonus, or resting position, resulting in attenuated performance on a sustained visual resolution task.

A general discussion regarding accommodative processes will clarify the necessary terminology and will be followed by a description of the general and visual characteristics of MS.

Resting Position

The ability of the crystalline lens of the eye to change its refractive power so that images of targets at various planes in depth are brought into clear focus on the retina is an important contribution to overall visual performance. This process is referred to as accommodation. Variations in lens shape are controlled by the ciliary body, a structure composed of smooth muscle and zonular fibers that attach the lens to the globe of the eye. An increase in the curvature of the lens causes it to become relatively spherical, focusing near stimuli. A decrease in lens curvature causes the lens to become relatively flat, focusing distant stimuli.

Under degraded visual conditions, accommodation tends to move spontaneously to an intermediate focus condition referred to as the resting position (Leibowitz & Owens, 1975). (Alternate terms for this concept are dark focus or tonic accommodation.) Although accommodative response is not accurate throughout its range (Johnson, 1976), responses to targets are most accurate near an individual's resting position. There is a quasilinear decrease in accommodative accuracy on either side of the resting position. Thus, for targets on the far side of the resting position over-accommodation occurs (accommodative lead); whereas for targets on the near side of resting position under-accommodation occurs (accommodative lag). Therefore, accommodative error occurs when an individual is focused in front of, or behind, the stimulus, resulting in a defocused image.

Classical theories (e.g. Helmholtz, 1909) assumed that the accommodative resting position was at optical infinity, or the observer's far point (the furthest point that an individual can focus). Active accommodation was considered necessary to clearly image near targets on the retina, and relaxation of accommodation was considered necessary to form clear images of distant targets. However, Schober (1954b) observed that the muscles controlling accommodation, as with other muscles, should not be expected to assume a resting or tonus position at one end of their range. Modern researchers generally agree that the resting position does not correspond to infinity but rather to an intermediate distance and that active effort is needed for both nearer and farther focusing.

Therefore, resting position is considered the least fatiguing accommodative state and the area of maximal retinal image quality. Each individual has a characteristic dark focus that serves as a reference point for the accommodative response in the absence of an adequate stimulus. Accommodative responses are measured in diopters (D). This is an index of refractive power that is the reciprocal of the lens's focal length in meters.

Leibowitz and Owens (1975) found that the mean resting position value was 1.5 D of myopia. Their data also indicated that subjects varied widely in the value of their resting position, ranging from optical infinity (0 D) to as much as 4 D of accommodation. This large intersubject variation has been the subject of investigation to determine whether the refractive properties of the eye are related to these individual differences in resting position. Although somewhat inconclusive, a tendency for a closer resting position of accommodation in hyperopia and farther in myopia has been found in some studies (Maddock, Millodot, Leat & Johnson, 1981; Heron, Bahri, Burnside, Kacouli & Mackintosh, 1984; McBrien & Millodot, 1987).

Baker, Brown and Garner (1983) showed that the accommodative resting position might be better described as a zone of approximately 1 D width. Although Ebenholtz (1983; 1985) demonstrated that the of resting position can be influenced by previous visual experience, Mershon and Amerson (1980) reported that there exists a remarkable degree of individual stability in dark focus over time.

Normal accommodation represents a compromise between the stimulus position (the required focal effort) and the individual's resting position. Johnson (1976) measured accommodation and visual resolution at a variety of luminance levels and stimulus distances. Errors of accommodation were small at higher luminance but became more pronounced with lower luminance, indicating an overall decline in visual resolution with reductions in luminance. However, this result is largely accounted for by changes in pupil size and changes in image contrast. Visual resolution also varied with stimulus distance, obtaining maximal resolution at the intermediate distance and degraded resolution for both nearer and farther distances. Lindblad, Raymond, Leibowitz and MacDuffee (1984) obtained similiar results when examining contrast sensitivity as a function of viewing distance. These results suggest that prediction of performance will be most accurate when viewing distance corresponds to the accommodative resting position of the observer.

Characteristics of the Accommodative Response

For an accommodative response to occur, impulses are initially delivered to the fovea centralis. Fibers from the nasal retinal surface cross through the optic chiasma; however, fibers from the temporal retinal surface do not. The cells of the lateral geniculate body receive the signal and relay it to area 17 of the primary visual cortex. These cells in the primary visual cortex project to the secondary visual cortex (area 18). The secondary visual cortex then relays the signal throught the internal sagittal stratum to the pretectal area. Cells of the pretectum establish connections with the nucleus of Edinger Westphal where efferent projections of preganglionic fibers pass via the oculomotor nerve to reach the ciliary ganglion. Some of these fibers induce the ciliary muscle to contract, thereby releasing tension on the suspensory ligament of the lens. This brings the image into focus on the lens by altering its focal length. To increase depth of field, other connections induce pupillary constriction.

Although the ocular mechanisms of the human accommodative response are reasonably well understood, the role of stimulus factors in eliciting the response are not. Following a change in target distance, the need to alter the lens power must be signalled via a feedback loop. As shown by Ward (1987) in Figure 1, the terminology of control theory has been used to conceptualize the mechanisms of the feedback loop. The desired lens power serves as the input to the

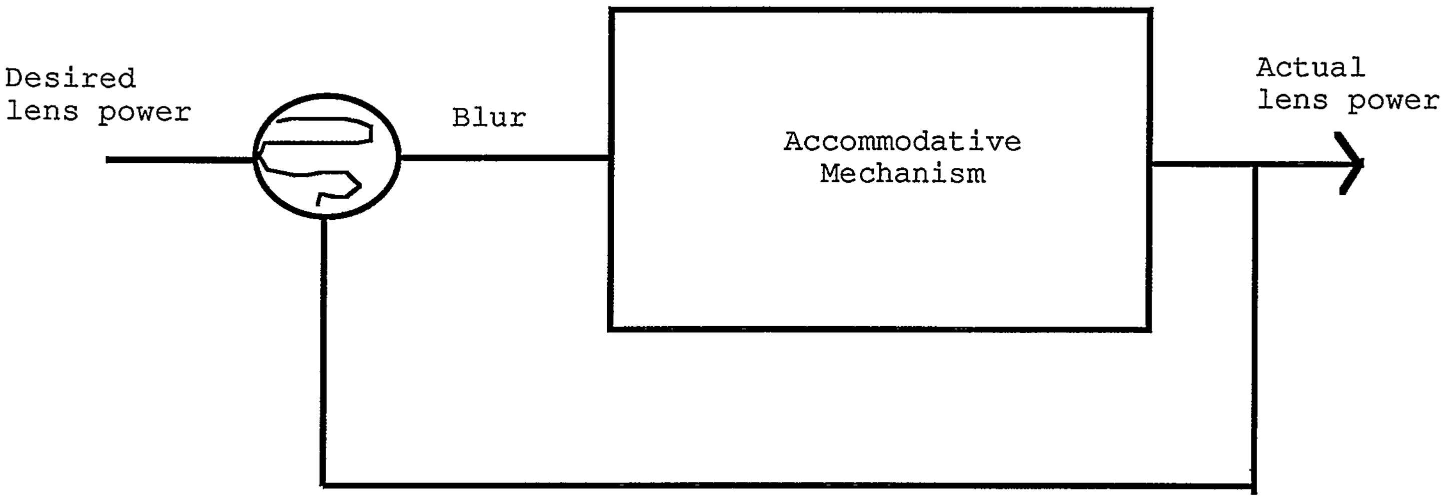

Figure 1. Simplified representation of an accommodative control system.

system and the accommodative response serves as the output. The output and input are compared via a feedback loop and the result is the error signal. The error signal provides information to the accommodation system which then modifies output.

Therefore, defocus results in alterations that reduce visual sensitivity and impair the sensory system's ability to detect stimuli. Past research suggests that the central mechanisms responsible for executing appropriate accommodative responses depends on the ability of the visual system to extract and utilize information regarding image contrast (Heath, 1956; Alpern, 1958; Toates, 1970; Owens, 1980; Raymond, Lindblad & Leibowitz, 1983; Ward, 1987).

The contrast sensitivity function (CSF) measures the minimum contrast required for the detection of a sine wave grating pattern which varies as a function of spatial frequency. Sensitivity is maximal for medium spatial frequency patterns and is attenuated for both higher and lower spatial frequencies.

Heath (1956) first demonstrated the importance of spatial contrast as an accommodative stimulus. He replicated the earlier work of Reese and Fry (1941) which suggested that if the image was sufficiently fogged the eye would return to its resting state. Heath degraded the contours of the accommodation target with lacquered lenses and found that as the contours and contrast of the target were degraded there was increasing under-accommodation for near and over-accommodation for far. It is important to note that he used Snellen targets which contain a large spectrum of spatial frequency information.

However, the findings of Raymond, Lindblad and Leibowitz (1984) indicate that more contrast is required to stabilize accommodation than is required to simply detect a pattern. More recently, Ward (1987) showed that accommodative response on the near side of the resting state is not greatly influenced by contrast while a greater effect occurred on the far side.

Campbell, Robson and Westheimer (1959) demonstrated that when an individual steadily views a near target the refractive power of the eye constantly undergoes fluctuations in crystalline lens power, that is, the lens is not stationary but shows oscillations in power. They hypothesized that these microfluctuations cause fluctuations in the contrast of the retinal image that can be detected by the visual system. Therefore, a cue to direction of defocus could be gained since the contrast changes would be either positive or negative relative to the mean modulation level. Alpern (1958) concurs that these oscillations provide necessary focusing information, postulating an accommodation oscillation from 'just perceptibly blurred' to 'clear'. These findings suggest that the ability to respond to defocus is a definite factor in stabilizing the accommodative state. Campbell (1960) indicated the fluctuations were very similar in both eyes and are therefore presumably of neural origin.

Thus, change in retinal image contrast is a critical stimulus for eliciting an accommodative response (Toates, 1970). Poor control of accommodation, which results in defocused retinal images, produces loss of contrast for higher spatial frequency components.

The utility of spatial frequency information as accommodative stimuli has also been examined. Charman and Tucker (1977) found that accommodative accuracy increased as the spatial frequency of the target was increased (up to a limit of 23 cycles/degree). However, Owens (1980) measured accommodation responses for grating stimuli at a range of spatial frequencies and found optimum performance for both accommodation and contrast sensitivity for intermediate spatial frequencies (3 to 5 cycles/degree), with attenuated performances for lower and higher spatial frequencies. The differences in these two sets of results may be attributed to differences in methodology. Bour (1981) used an infrared optometer and reported findings consistent with those of Owens.

Charman and Heron (1979) suggest that when an individual is presented with a target which demands an accommodative response, the response is first guided by the changes in contrast in low spatial frequency components in the retinal image and is then refined using the higher spatial frequency information. Thus if the eye is initially accommodated for objects at some fixed distance, the presentation of the target at a different distance will result in the formation of an out-of-focus retinal image. This image will have reduced contrast for the higher spatial frequencies.and the image will be perceived to be defocused. Depending on the degree of defocus, the reduction in contrast may be substantial enough to make the high spatial frequency components subthreshold.

Only low spatial frequency information can initially be perceived in the out-of-focus retinal image. Therefore, the initial accommodation response can be based only on this low spatial frequency information. As the response brings the image closer to the optimal focus, higher frequency information acquires more contrast and can therefore permit a further refinement in the response. Thus accommodation seems to proceed sequentially, using first lower and then higher spatial frequency information until changes in focus cannot be perceived (Toates, 1970; Charman & Heron, 1979).

In sum, reduction of either the luminance (Johnson, 1976) or the contrast (Heath, 1956; Alpern, 1958; Toates, 1970; Raymond, Lindblad & Leibowitz, 1983; Ward, 1987) of a visual stimulus results in systematically increasing errors of accommodation. For most observers, this diminished focusing accuracy is seen as simultaneously increasing myopia for distant stimuli and increasing hyperopia for near stimuli (Johnson, 1976).

Because accommodation relies on the retinal image to produce a response, the information is limited by the constraints of the optical system and the resolving power of the neural system. Therefore, other important factors controlling the accommodation system are aberrations in the retinal image (Kruger & Pola, 1986) and pupil size (Hennessy, Iida, Shiina & Leibowitz, 1976; Ward & Charman, 1987). Reducing pupil size increases the depth-of-field and reduces ocular aberration. High spatial frequencies are attenuated to a greater extent by any given amount of defocus than lower spatial frequencies; hence, as pupil size is reduced the higher spatial frequency content of the image is reduced.

Sustained Detection

Accommodative fatigue, which may be reflected as a loss of control, and thus a drift back to the resting position, would be expected to occur more frequently as the distance between the stimulus and the accommodative resting position increased. The resulting defocus would reduce retinal image contrast, and therefore, impair perception, particularly of high spatial frequency information. Functionally, this would suggest that if adequate focus is not maintained, a reduction in contrast sensitivity and visual resolution should result.

Therefore, maintaining detection of a stimulus will depend on the ability to sustain the focused image. Many visual tasks in daily life demand resolution of detail for long periods of time. Maintaining detection of stimuli requires the continuous availability of a well-focused, high quality retinal image. However, conventional behavioral techniques (i.e. threshold tasks) used to assess visual function depend on transitory detection or recognition of stimuli. Viewing stimuli at distances nearer to or farther from the distance corresponding to the individual resting position of accommodation is probably associated with an increased accommodative effort and poor maintenance of accommodation. Sustained accommodation to objects at distances other than the resting position would therefore be subject to fatigue. Previous research (Raymond, Lindblad & Leibowitz, 1983; Raymond & Leibowitz, 1985) found that fluctuations in stimulus visibility were attributable to transient losses in accommodative accuracy.

Raymond, Lindblad and Leibowitz (1984) asked subjects to operate a timer and indicate whenever a high contrast, high spatial frequency grating pattern was visible over a one-minute interval. Under normal viewing conditions the detection of the grating was discontinuous but when accommodation was paralyzed, detectability of the stimulus was stable only at resting position. This indicated that transient losses of accommodation could be used to explain the fluctuations of grating visibility.

Additionally, Raymond and Leibowitz (1985) found that sustained detection of a high spatial frequency grating varied with accommodative stimulus distance, peaking at an individually determined point which corresponded to the individual's resting position. They hypothesized that increased accommodative effort was demanded outside of resting position. Thus, viewing stimuli at distances other than resting position resulted in a drift of accommodation toward the resting position. This accommodative error would cause a loss of retinal image contrast relative to the difference between the stimulus distance and the individual resting position. They concluded that momentary prediction criteria were not predictive of the capacity to maintain detection and, as a result, overestimated the capacity to utilize visual stimuli.

Sustained accommodation has been investigated using a different psychophysical technique (Raymond, 1986). With this procedure the subject was asked to view an alphanumeric character displayed on a monitor for a short interval. The stimuli were presented in a Badal optical system so that accommodative distance could be changed without changing image size or brightness. At a randomized time during the interval the stimulus was subtly changed into another alphanumeric character. The subject's task was to fixate on the stimulus and to press a button as soon as s/he detected a letter change. This was heavily dependent on an appropriate accommodative response. Therefore, if accommodation were accurate at the time of the character change, the reaction time of the subject would consist of the time needed to process and respond to the necessary visual, cognitive and motor components of the task. If, however, the subject was not accommodated at the time of the transformation, the reaction time measure would also include the amount of time that the character change was undetected as well as the necessary time required for accommodative adjustments permitting resolution. Because the process of accommodation requires several hundred milliseconds (Westheimer, 1974), reaction time should be shortest when accommodation is accurate and longer when accommodation is inaccurate. If the subject had maintained accurate accommodation on the stimulus, reaction times were expected to be short. If however, accommodative control was poor and drifted away from the stimulus location, reaction times were expected to be longer.

As hypothesized, in the sustained detection task, individual reaction times to detect the change in the alphanumeric stimulus were lowest at an idiosyncratic optical distance and rose as the difference between the viewing distance and this point increased, for both near and far optical distances. It was assumed that this minima corresponded to the resting position of accommodation. This minima also corresponded to lower variability of response and lower error scores, indicating that the task was less effortful at this distance. Raymond (1986) emphasized that the high variability observed at some optical stimulus distances suggests that detectability of a suprathreshold stimulus can fluctuate over time.

In summary, sustaining detection of a stimulus outside of resting position is effortful and subject to fatigue.

This fatigue is reflected in a return to resting position, causing the retinal image to defocus. Blurring or "fogging" of vision is a frequently associated symptom of multiple sclerosis in spite of normal or near-normal visual acuity scores. In addition, multiple sclerosis is associated with rapid fatigue on exertion; hence, it is expected that the multiple sclerosis patient would have an impaired capacity to sustain accommodation outside of resting position which would result in attenuated performances at particular viewing distances. The following discussion will address general characteristics of multiple sclerosis as well as associated visual problems.

Multiple Sclerosis

Multiple sclerosis is a chronic disease affecting the white matter of the central nervous system. It is characterized pathologically by numerous discrete areas of demyelination along the course of involved axons and clinically by a variety of neurological symptoms and signs which have a tendency toward remission and exacerbation. Discrete areas of myelin loss are believed to cause a slowing and block of neuronal conduction which is, in turn, responsible for the clinical signs. The cause and pathogenesis of this disease remain unknown. No preventive measures or definitive therapies exist.

The average age of onset is 32 years with a distribution skewed somewhat toward the older ages. In 95% of cases the disease begins between the ages of 10 and 50 with an additional 5-6% of disease occurrence between the ages of 50 and 60. The reason for this age susceptibility is unknown. Speculations relate it either to direct viral infection acquired in adolescence, with an average incubation period of about fifteen years, or to a greater tendency to experience allergic reactions of the brain during young adult life. Younger patients who develop MS tend to have more intracranial lesions and a higher frequency of exacerbations, whereas patients with late onset MS are more likely to have a progressive spinal cord disease (Sibley, Bamford & Clark, 1984). Female to male ratios range from 1.4:1 - 2:1:1. Broman, Anderson and Bergman (1981) believe that some of the higher ratios noted in prevalence studies are due to a greater mortality rate in males with MS. Moreover, its occurrence lends support to the view that MS may be a disorder of immune regulation (i.e. almost all autoimmune diseases are more common in women).

Epidemiologic studies of MS have shown geographical regions of high and low prevalence. Northern Europe, the northern United States and southern Canada, as well as southern Australia and New Zealand represent areas of high prevalence (with a frequency ranging from 58 cases per 100,000 to 130 cases per 100,000). Regions of low risk include most of Asia and Africa and have a prevalence of 5 or fewer cases per 100,000. The highest concentration of MS-prone populations is found in Scotland, in the Shetland and Orkney Islands (with a frequency of 309 cases per 100,000). This risk is not defined at birth. Place of birth and residence during the first 15 years of life are important in terms of MS risk. Migrants from areas of higher risk to areas of lower risk acquire the lower risk, provided that migration occurs before the age of fifteen. However, if migration occurs after the age of fifteen there appears to be a greater risk for MS. Conversely, people migrating in childhood from an area of low risk to an area of high risk acquire the increased risk. The geographic distribution of multiple sclerosis and the studies of migration suggest that the disease is acquired from an environmental factor. Multiple sclerosis was unknown in the Faroe Islands before 1940 but 24 cases were recorded in the years after the British troops were garrisoned there. It seems clear that an infectious agent was involved (Paty & Poser, 1984).

Racial and familial factors also appear to influence incidence. Multiple sclerosis is primarily a disease of northern European racial stock; it is less common in persons of southern European stock, Orientals and native African blacks and is virtually unreported in Eskimos, pure Bantus, Yakus and Gypsies (Rivera, 1986). Paty and Poser (1984) suggest that familial occurrence may be caused by the same factors that produce varying racial suseptibilities. (i.e. these familial and racial risks are probably determined by the histocompatibility (HLA) genotype, with certain patterns producing an increased susceptibility). However, they note that the HLA linkages found in population surveys have not been consistently seen in family studies. No evidence exists that MS is directly inherited, although it develops 12 to 15 times more readily among first degree relatives of affected individuals than in the population at large. Higher concordance rates occur in fraternal twins as compared to siblings and sibling pairs tend to acquire the disease at approximately the same point in the calender year, in spite of age differentials (Eber, 1984). It is now conventional to theorize that MS can be initiated by viral infection in genetically susceptible individuals (Newmark, 1985).

Other data would seem to suggest that MS may be a post infectious phenomenon and indicate that the environmental triggers of MS worsening are not entirely unspecific (Sibley, Bamford & Clark, 1984). For example, it is possible that MS might be related to viral infection as a postinfectious phenomenon. Sibley et al. (1984) found in a prospective study that infection is frequently lower in patients than in controls; moreover, the frequency of infections was inversely related to the degree of MS disability in an almost linear fashion. It seems plausible therefore that MS patients have heightened immune defences.

Microscopically, the characteristic feature is the breakdown of the myelin sheath. Although swelling and degeneration of axons may occur, these structures are characteristically spared. Although complete Wallerian degeneration (in which both axons and myelin are destroyed) is infrequently observed, it has been noted, particularily in advanced stages of the disease or in the severe lesions of the acute form. However, the predominant change is the destruction of myelin (McDonald, 1974).

The cause and pathogenesis of multiple sclerosis remains unknown. However, there is strong evidence that immune abnormalities are related in some way to the disease (Waksman and Reynolds, 1984). One concept is that MS is the result of a slow infection. However, thorough examination of MS tissue has not revealed any infectious organisms. McFarlin and McFarland (1982b) qualify this by noting that previous studies have demonstrated that it is possible for virus genetic material to persist within the nervous system even though viral particles cannot be visualized.

The primary pathology is confined to the central nervous system, where macroscopic lesions ranging from 1 mm to 4 cm are scattered throughout the white matter (McFarlin & McFarland, 1982a). These are known as plaques. Plaques of demyelination may be found throughout the brain and spinal cord, although they are most prevalent in the cerebrum, brainstem, cerebellum, and spinal cord (Poser, 1979).

Thus it can be hypothesized that the disease is caused by an infection caused during childhood, persisting in proviral form and subject to episodic activation. Alternately an infection occuring in childhood could induce a change in immune function and initiate an autoimmune disease against the nervous system. Multiple sclerosis could also be more than one entity caused by more than one pathogenic mechanism. Poser (1979) argues that it is unlikely that a single specific viral agent is responsible for the disease and claims that even if a virus can be proved to be implicated in multiple sclerosis, it is likey to be merely the initiator of a chain of immunological events leading to the demyelination of nerve fibers rather than a direct cause.

He hypothesizes that the initial viral infection somehow triggers an autoimmune reaction against components of the myelin sheath of nerves. How the disease progresses from this triggering event is unclear.

In 70% to 90% of MS patients there is a relapsing and remitting course in which the recovery following each episode is complete. The frequency of relapses is totally unpredictable. A recurrence of symptoms cannot be taken as evidence of an acute relapse - they are likely caused by metabolic or physiologic influences on a previously damaged and demyelinated area of the central nervous system.

In 30% of MS patients a chronic progressive course is present from the outset. This is more common in older patients, particularily older men. Most of these patients have a chronic spinal form, although progressive cerebellar and cerebral syndromes are not uncommon.

At least 20% of MS patients have a benign course. This means an average life span of relatively normal activities. This particular course cannot be predicted early in the disease, but it is more likey to be present in patients with a younger age of onset.

Fewer than 5% or 10% of patients run a very malignant clinical course. It is characterized by severe relapses during the first year followed by early chronic progressive deterioration. These patients can be severely disabled or dead within a few years of the first symptom. When this occurs it is usually in patients with a younger age of onset.

The hallmark of MS is the presence of multiple lesions scattered in the white-matter pathways of the CNS. The mode of onset is extremely variable, as is the clinical course. Symptoms may develop rapidly over a period of days or may take weeks to reach their maximum. Poser (1979) argues that the symptoms and signs of multiple sclerosis may indeed result from the formation of plaques, but points out that it is now clearly understood that they may also result from physiologic alterations (e.g., heat, calcium concentration) affecting previously existing plaques. In addition, he argues that other mechanisms should also be considered: since symptoms and signs may be the result of swelling rather than the destruction of myelin. Other possibilities include recurrence of edema in the same location or the enlargement of a previously exising plaque. Therefore, it would seem that clinical exacerbations can with equal probability represent either physiologic alterations or evidence of the production of new plaques, or the expansion or reactivation of old ones.

Cortico-spinal tract involvement is frequent, so that the patient complains of fatigue, heaviness, clumsiness and weakness of a limb and exhibits hyperreflexia and extensor toe signs. Either at the outset or later, many patients develop facial numbness or palsy, vertigo, truncal and limb ataxia, bladder symptoms or impotence (Seland, 1984).

"An unequivocal diagnosis of MS is possible only at autopsy" (Seland, 1984; pg. 1499). The early diagnosis of multiple sclerosis is difficult in some patients because of the nonspecificity of the usual symptoms and the paucity of neurological findings. Criteria for the clinical diagnosis of multiple sclerosis have been developed. The application of strict criteria for the diagnosis of definite, probable and possible cases of multiple sclerosis is important in order to avoid safegaurd diagnosing this disease in a patient who may be suffering from another medical or neurologic condition, anxiety or depression.

These criteria require objective evidence of central nervous system dysfunction on neurological examination and either historical or objective indications of involvement of the neuraxis at two or more levels. The temporal profile must either be of two or more episodes lasting more than 24 hours and separated by at least one month, or of gradual or stepwise progression over the last six months. A definite diagnosis of the disease requires documentation of lesions that have occurred on more than one occasion and at more than one site, and that are not explained by other mechanisms. Precision in the diagnosis of MS is critical for patient management and in order to gain understanding of the aetiology and pathogenesis of the disease and for the development of effective treatments (McDonald & Halliday, 1977). Common procedures used to aid the clinical diagnosis of multiple sclerosis include electrophysiologic studies, computerized tomography, cerebral spinal fluid examination, blood leukocyte evaluation, study of histocompatibility., and nuclear-magnetic-resonance imaging.

Visual Involvement in Multiple Sclerosis

Involvement of the visual pathways, although many times asymptomatic, are present in more than 90% of multiple sclerosis (MS) cases. Neuro-opthalamic signs and symptoms are often critical in establishing a diagnosis and occur in most patients at some time during the course of the disease. The characteristic visual signs and symptoms of MS will be outlined in the following discussion.

Optic Neuritis. If a previously healthy person experiences occurrences of acute optic neuropathy a relatively high risk of future demyelination in the central nervous system is established. In 16% to 30% of patients (Paty & Poser, 1984) the first symptom of MS is optic neuritis (ON). This is an acute or subacute monocular loss of central vision with peripheral sparing. It is generally associated with retrobulbar pain on movement of the globe that evolves into a mild to severe visual deficit. Although occasionally the loss is permanent, most patients experience complete recovery over a period of weeks or months. Fifty percent of patients with isolated ON go on to develop clinical MS (Paty & Poser, 1984). In 75-90% of cases the interval between the onset of ON and the diagnosis of MS is ten years (Paty & Poser, 1984).

Neuro-Ophthalamic Signs and Symptoms

Eye Movement Disorders. Almost all varieties of nystagmus have been described in MS in addition to subclinical eye movement abnormalities (for review see Ellenberger & Daroff, 1984). Abnormal velocities, abnormally delayed saccadic initiation times, abnormal saccadic accuracy and impaired pursuit have all been described. Researchers suggest that these symptoms might be useful in identifying silent second lesions in cases of suspected MS.

Fundus. The diagnostic relevance of the appearance (i.e. abnormal pallor) of the ocular fundus remains controversial. Nevertheless, most clinicians continue to rely upon the degree of disk pallor to make assessments rather than upon abnormalities of visual function. Normal optic disks vary in their color and retinal illumination magnifies this difference during fundus photography. Recently clinicians have begun to examine the retinal nerve fiber through a dilated pupil using red-free illumination. This assesses the presence or absence of a full complement of ganglion cell fibers. This enables the examiner to more accurately assess the degree of axonal loss than by attempting to quantify disk pallor.

Internuclear Ophthalmoplegia. Multiple sclerosis is the most common cause of internuclear ophthalmoplegias (INO) in young adults and an acute bilateral INO is virtually pathognomonic of the disease. INO is characterized by impairment of versional aduction secondary to a lesion in the ipsilateral medial longitudinal fasciculus between the sixth and third cranial nerve nuclei. It is characterized by nystagmus of the abducting eye, with paresis of the adducting eye in the lateral horizontal gaze. Although diplopia is seen as an initial symptom in only 13% of MS patients (Paty & Poser, 1984), this syndrome usually produces diplopia. If nystagmus is greatest in, or limited to the abducting eye, an examination of optokinetic function is the most sensitive clinical test to prove an INO if an impaired adduction is also documented. Other asymmetric nystagmus signs may be physiologic (Abel, Parker, Daroff & Dell'Osso, 1978) or caused by drugs.

Pupillary Defect. Relative afferent pupillary defect is a valuable and reliable diagnostic sign for impaired function in one optic nerve However, patients with large retinal lesions or suppression amblyopia can exhibit small afferent defects. Measuring the magnitude of the afferent defect with neutral density filters can be shown to parallel the amount of visual field loss (Thompson, Montague, Cox & Corbett, 1982).

Visual Signs and Symptoms of Multiple Sclerosis

Visual Acuity. Ellenberger and Daroff (1984) maintain that the test for visual acuity remains one of the best measures for obtaining information about the integrity of the visual neural system. As such, they suggest that if acuity is abnormal in one or both eyes and optical and retinal causes can be eliminated a conduction abnormality can be diagnosed. However, Frisen and Frisen (as cited ny Ellenberger & Daroff, 1984) have demonstrated that with only 11% of the conducting axons intact an individual can resolve a 20/40 letter. Thus it can be concluded that extensive demyelination would not be expected to cause large reductions in acuity and that a small change in acuity could be a critical indicator of disease.

Color Defects. Patients recovering from an attack of optic neuropathy or who are experiencing slowly progressive visual loss frequently report that colors appear desaturated to the affected eye. When congenital color deficiency can be excluded, a reduced score on pseudoisochromatic color plates may indicate acquired optic neuropathy. Although criteria for normalcy are not precise, scores obtained with pseudoisochromatic test plates can be considered as a rough measure of the degree of visual loss.

Visual Fields. Although most patients recover a substantial amount of their vision after an attack of acute ON, minor residual abnormalities in vision remain. However, standard perimetry is not effective for testing these residual effects. When tested by the usual methods of kinetic perimetry most patients who have recovered from an attack of optic neuritis will have normal visual fields (D'Cruz & Ellenberger, 1983). Static perimetry is more effective than kinetic perimetry in detecting the generalized reduction of sensitivity due to a probable reduction in the total number of conducting axons. The optic nerves appear particularily vulnerable to this demyelinating process. Visual defects of the optic chiasm, tracts and optic radiations are rare. It is plausible that more uniform involvement of the entire extent of the visual pathways occurs with a longer duration of the disease. However this greater loss of visual sensitivity to static than to kinetic targets is not specific to demyelinating disease.

Adaptation. Patients often report a visual reduction in brightly lit environments unless they wear tinted lenses. Moreover, vision can be restored by spending time in darkness. Additionally, patients with all types of optic neuropathy report that a stabilized image on the retina disappears more quickly than do patients with normal vision. This reduced sensitivity to stationary stimuli, presumably relates to abnormally rapid focal adaptation to a visual stimulus.

Flight of Colors. A predictable sequence of afterimages occurs after a bright light is shone into a patient's eye for 10 seconds or longer. Feldman, Todman and Bender (1974) noted that this "flight of colors" was good in most normal subjects but only fair to absent in patients with visual system lesions. Mourik, vanDonsellar and Minderhoud (1978) found that 74% of MS patients demonstrated a disturbed flight of colors.

Temporal/Spatial Vision and Multiple Sclerosis

Psychophysical tests are physical measures of sensory function. Psychophysical investigations of the visual abilities in patients with MS have shown that these patients frequently experience deficits in both the spatial and temporal domains. The objective of psychophysical studies has been to uncover subtle visual deficits that may result from the neurophysiological effects of demyelination on axonal conduction.

Temporal Vision. Regan (1981) suggested that slowed or blocked axonal conduction in the optic pathways should cause observable delays in visual perception. Using the 'delay campimetry' technique Heron, Regan and Milner (1974) and Regan, Milner and Heron (1976) examined simultaneous judgements for the perception of light intensity. In order for an MS patient to perceive the onset of two lamps as simultaneous, the brightening of one lamp had to temporally precede the other. In spite of the appearance of normal acuity on all standard visual clinical tests, they found abnormal delays (greater than 2 standard deviations) in all patients tested. They noted that delayed visual signals could be regarded as reliable "signatures" of previous attacks. Different distributions of abnormal delay values across the visual fields were found with some MS patients when dimming rather than brightening of the lamps was used. Regan et al. (1976) suggested that channels sensitive to the dimming rather than brightening were differentially affected by MS.

Rushton (1975) developed a method for detecting abnormal visual delays in MS patients using the Pulfrich pendulum effect. The Pulfrich stereoillusion occurs when a pendulum swinging from side-to-side appears to assume an elliptical path after a neutral density filter is placed before one eye. This effect has been attributed to an increase in visual latency of the attenuated eye. This same illusion appears when demyelination causes a differential between the conduction velocities of the two optic nerves. Wist, Hennerici and Dichgans (1978) found that a moving grating pattern as a stimulus increased the sensitivity of the test.

Critical flicker fusion (CFF) frequency has also shown to be reduced in patients with MS (Parsons and Miller, 1957; Titcombe and Willison, 1961). CFF is the rate, in cycles/second, of successive light flashes from a stationary light source at which the sensation of flicker disappears and the light becomes "steady". In addition, the "double-flash" test, that is, a patient's ability to detect that two closely following flashes of light are double rather than single is also impaired. Galvin, Regan and Heron (1976) and Galvin, Heron and Regan (1977) demonstrated that by increasing the interval between flashes an MS patient's perception of a double flash can be restored. Changes in thresholds could be induced by elevating and lowering body temperature (Galvin, Regan & Heron, 1976b).

Abnormal delays in the transmission of visual information has also been found using evoked potential recording methods (Milner, Regan & Heron, 1975). The latencies of the average visual responses evoked by checkerboard pattern reversal stimulation are abnormally long in the affected eye of patients with optic neuritis.

Spatial Vision. From the results of previous research (Bodis-Wollner & Diamond, 1976; Regan, Silver & Murray, 1977; Zimmern, Campbell & Wilkinson,1979) it appears that certain disorders of vision are associated with an abnormality of the contrast sensitivity function (e.g.lesions to the visual cortex, glaucoma, amblyopia). In demyelinating diseases such as multiple sclerosis it would appear that particular spatial frequency channels are damaged, thereby impairing sensitivities to certain frequencies. These are detected as abnormalities of the contrast sensitivity function. Thus an abnormal contrast sensitivity function reflecting disturbances in certain spatial frequency channels will lead to faulty visual information processing. This could greatly affect pattern recognition without affecting Snellen acuity.

MS patients often complained of 'washed-out' and/or blurred vision in spite of normal visual acuity. Regan, Silver and Murray (1977) reasoned that refractive error had no such effect and hypothesized a neural defect. Snellen acuity procedures test only high spatial frequencies; therefore, a CSF was derived for each patient in order to test sensitivity to a range of spatial frequencies. Regan et al. (1977) demonstrated that some MS patients show losses in the ability to detect low contrast sine wave grating patterns. Moreover, they found that these losses in contrast sensitivity were often specific to the spatial frequency of the grating pattern. The existence of losses in contrast sensitivity specific to spatial frequency in MS patients have been confirmed by Ginsburg (1977) and Zimmern, Campbell and Wilkinson (1979). Some patients show orientation-specific losses of contrast sensitivity (Regan, Whitlock, Murray and Beverley, 1980).

Regan, Raymond, Ginsburg and Murray (1980) further investigated the perceptual effects of losses in contrast sensitiviy for specific spatial frequencies and orientations. They measured MS patients' ability to discriminate letters. They 'spatially filtered' the letters in order to contain all spatial information within a narrow range of spatial frequencies. Low, medium or high spatial frequncies were employed in the task by adjusting the viewing distance. The critical range of spatial frequencies required to make the discrimination were adjusted to different positions along the spatial frequency continuum. They were able to successfully predict the performance of these patients from their CSF data for the discrimination task. When the spatial frequencies required to perform the task were the same as the spatial frequencies for which contrast sensitivity was reduced, MS patients' ability to discriminate the stimuli was impaired.

Medjbeur and Tulunay-Keesey (1986) argue that threshold abnormalities do not provide a complete description of the visual dysfunctioning in patients with demyelinating disease and maintain that the way in which these patients perceive suprathreshold stimuli is more appropriate for predicting the quality of day-to-day vision. Their results suggest that an enhanced "compensation" mechanism operates in the spatial frequency region affected by threshold loss. In contrast, Hess and Plant (1986) found similar threshold and suprathreshold contrast deficits. Although these differences appear attributable to methodology, further research in the area of suprathreshold response is necessary.

Summary

Accommodative resting position values should not be abnormal in most MS patients. However, MS patients should have more difficulty sustaining the accommodative response needed to focus and that accommodative fatigue might serve as a possible explanation for contrast sensitivity deficits in some patients. Loss of strength in a prolonged motor activity is a hallmark of MS symptoms. Thus differences in the capacity of patients to sustain an accommodative response are predicted. If patients fatigued more quickly than healthy controls, detection of stimuli requiring even a small amount of accommodative effort should be quickly degraded due to an unusually rapid return to the resting position. Since the neural pathways subserving accommodation are typically heavily demyelinated in MS cases examined at autopsy, it was hypothesized that accommodative problems might occur in a large proportion of MS patients.

Sustained accommodation will be measured at a variety of viewing distances relative to the resting position of accommodation. When the reaction time of healthy observers is plotted as a function of accommodative distance, it is hypothesized that a shallow 'V' function would be obtained with the minimum reaction time being found at distances corresponding to the resting position of accommodation. If poor accommodative control is characteristic of MS patients, steep 'V' functions are expected.

Resting position was measured using a laser optometer. In addition, the near and far points of accommodation were measured so that accommodative range could be assessed. Comparisons of sustained accommodation functions obtained from healthy individuals and those with MS were considered useful for determining the extent to which dioptric factors contributed to perceptual deficits in MS. Control for pupil size and Troxler fading were incorporated into the experimental procedure. Control experiments in which the lens was cyclopleged were also conducted in order to determine the contribution of accommodative factors.

It is expected that this research will provide some of the first quantitative data on accommodation in multiple sclerosis and would explicate the role of dioptric factors in this patient population.

Method

Subjects

Subjects consisted of a group of MS patient volunteers and a group of healthy subjects matched to patients for age, sex and time of testing. All subjects wore corrective lenses as required throughout the test. Data from 28 eyes was obtained and subsequently used in the analysis. Two patients suffered exacerbations between test sessions and consequently had only one eye tested and two patients were unable to complete the task with one eye (attributed to neurological impairment from optic neuritis). Control data matched for these patient's eyes were also eliminated from the analysis. All subjects gave informed consent for their participation.

Patients comprised 7 females and 2 males whose ages ranged from 23 to 34 years (mean = 30.3 years; SD = 3.5 years). All were diagnosed "definite multiple sclerosis" according to the criteria set out by Poser, Paty & Scheinberg et al. (1983), and were classified according to the disability scale of Kurtzke (1965). Clinical visual indications are summarized in Table 1. Indications included a history of optic neuritis (ON), pale optic discs, clinically evident nystagmus, abnormal contrast sensitivity functions and corrected Snellen visual acuity worse than 20/40. All patients were selected from the Multiple Sclerosis Clinic at the Calgary General Hospital.

Control subjects comprised 7 females and 2 males and all had corrected visual acuity of 20/40 or better and none had any known history of neurological disorder. Control subjects ages ranged from 23 to 35 years (mean = 30.1 years; SD = 3.7 years).

The average pupil diameter measured photographically during the test session was 4.25 mm for both groups (MS mean = 4.3 mm, S.D. = .49; Control mean = 4.2 mm, S.D. = .83).

Table 1. Visual Indications in Multiple Sclerosis Patients

	Sex	Age	Diagnosis	Visual Indicators
1	F	31.0	definite	diplopia, ARPD, abn. VER, optic atrophy
2	F	33.0	definite	ARPD, nys, abn. VER, optic atrophy
3	M	27.6	definite	ON (rt),pale optic discs, nys, abn VER, optic atrophy (rt)
4	F	33.2	definite	bilateral ON, ARPD (lft), pale optic discs
5	F	23.9	definite	ON (rt)
6	M	33.9	definite	bilateral INO,diplopia, nys abn VER, abn ABR
7	F	31.0	definite	ON (rt), abn VER (lft),optic atrophy (rt)
8	F	26.0	definite	none
9	F	32.0	definite	blurred vision

abn VER:	Abnormal Visual Evoked Response
abn ABR:	Abnormal Auditory Brainstem Response
ARPD:	Relative Afferent Pupillary Defect
nys:	Gaze Induced Nystagmus
ON:	Optic Neuritis
INO:	Internuclear Ophthalmolplegia

Apparatus

Range of Accommodation. The near and far points of accommodation were measured so that accommodative range could be determined. For assessing far point a Badal lens (+5 D) was positioned between the observer and the target so that target size and luminance remained constant despite changes in the optical distance of the grating (Rubin, 1977). The target was a black 20/40 Snellen E (73 cd/m^2) mounted on a white card for maximum contrast.

Resting Position of Accommodation. One channel of a two channel Badal optical system employed a laser optometer to measure the resting position of accommodation. With this technique (see Hennessy & Leibowitz, 1972 ; Owens & Leibowitz, 1975), a "speckle" pattern is produced by reflecting the diverged beam of a low output laser from the surface of a slowly rotating drum. If the subject is overaccommodated for the optical distance of the drum the speckles appear to move in the same direction as the rotation of the drum; if the subject is underaccommodated the speckles appear to move opposite the drum's rotation. When the drum is at an optical distance conjugate to the resting position, the speckles appear either stationary or indistinctly swirling.

A schematic diagram of the system is shown in Figure 2. Badal optics were employed to permit manipulation of the optical stimulus distance without altering image size. The subject's eye was positioned 20 cm anterior to a +5 D Badal lens. The object of the Badal lens consisted of the virtual image of the laser optometer formed by a minifying -10 D lens positioned in front of the laser. The beam of the laser optometer was reflected by a half-silvered mirror to the subject. The drum was moved along the optical bench toward or away from the subject and rotated at a rate of approximately 1 rpm. Movement of the optometer drum along

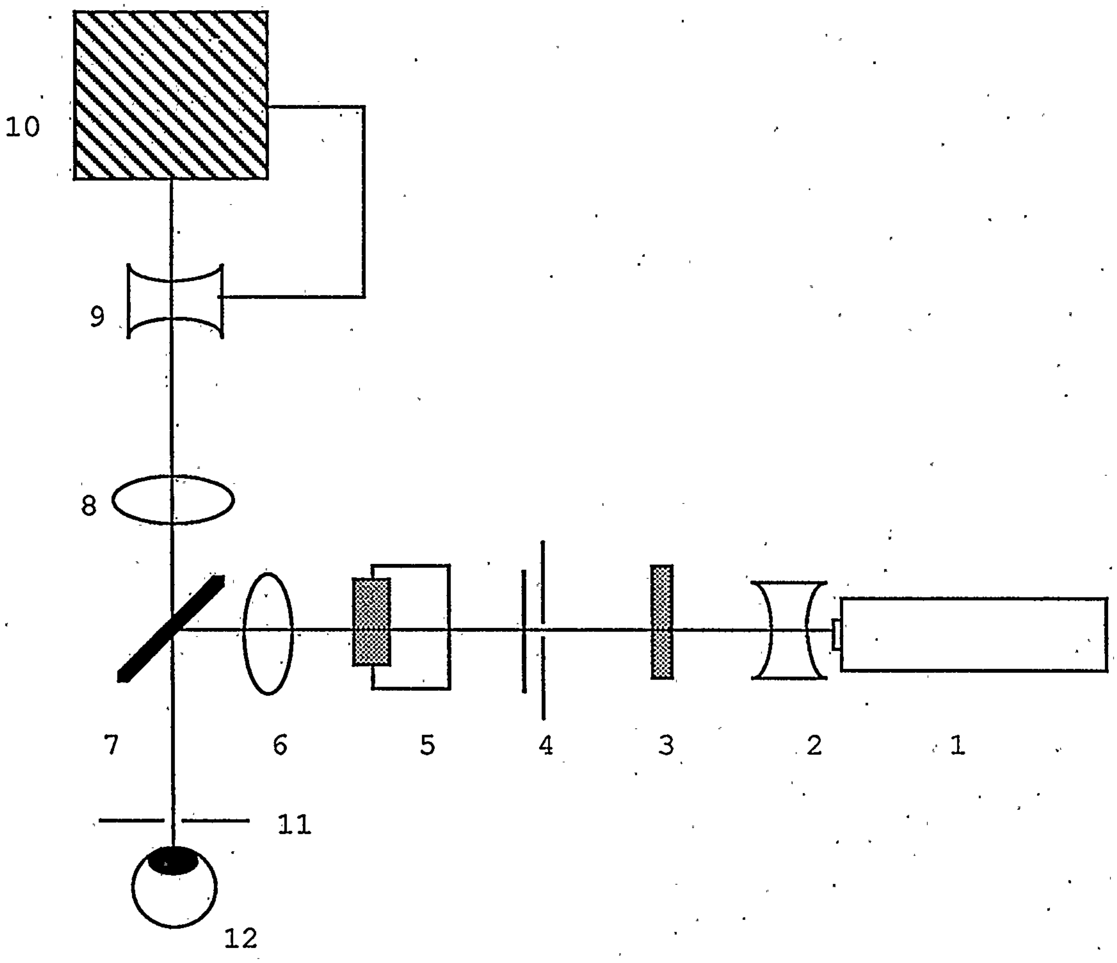

Figure 2. Two-channel Badal optical system.

1	laser optometer	7	half-silvered mirror
2	-10 D lens	8	+5 Badal lens
3	3.0 l.u. ND filter	9	-10 D lens
4	shutter	10	Zenith monitor
5	drum	11	Aperture
6	+5 D lens	12	Eye

the observing path until the speckle pattern appeared stationary allowed the accommodation state of the eye to be calculated from the drum position.

A neutral density filter (3.0 log units) was positioned between the laser optometer and the drum to adjust the luminance of the red (633 nm) beam to a more comfortable level. To obtain a measure of absolute accommodation from the monochromatic laser light, a constant (+0.33 D) compensated for the axial chromatic aberration of the eye.

Between stimulus presentations the stimulus field was occluded by a manually operated shutter. A shutter to a timing device gave a red speckle pattern presentation for 0.5 sec. The rate of presentation was irregular and was determined by the subject.

Head position was stabilized with a chin rest and forehead restrainer. The stimuli were monocularly observed. A circular field stop (1 mm in diameter) placed 7 cm in front of the eye produced an unfocusable field edge. As pupil size is reduced, accommodation is diminished (Hennessy,et al., 1976) and therefore an artificial pupil was used to control for pupil size. Moreover, Ward and Charman (1985) advocate the use of the artificial pupil in order to minimize ocular depth-of-focus and to optimize precision during the estimate of accommodation while maintaining the required small pupil for the target observation. Measures of resting position were obtained in a completely darkened room.

Pupil photographs were taken with a Pentax K1000 camera, a Pentax 50 (F 2.8) macrolens and a Starblitz 160A flash-unit. The camera was stabilized on a tripod. All photographs were taken in a darkened room while the subject was seated at the apparatus, focused on the sustained detection stimuli at its nearest point (3.98 D).

Sustained Detection. One of two alphanumeric stimuli were presented on a Zenith (ZVM-121) green phosper monitor. A microcomputer (Apple IIe) was used to control stimulus presentation and to record subject's response times (timing measurement error was approximately 1 msec). Each stylized stimulus (either an E or a 3) consisted of 17 pixels. Stimulus size corresponded to a 20/70-size Snellen letter. To transform one symbol to the other two pixels in the vertical segment of the character simultaneuosly extinguished and 16 msec later brightened in the opposite location. The luminance of the symbols, as measured at the monitor face with a spot meter (SEI), was approximately 43.1 cd/m^2. The luminance of the background was approximately 0.2 cd/m^2. Subjects responded by depressing a button on a microcomputer game paddle.

The stimuli on the monitor were viewed monocularly from the second channel of the two channel Badal optical system. Again, the Badal lens was employed so that stimulus viewing distance could be altered without causing an apparent change in the size or brightness of the image. The object of the Badal lens consisted of the virtual image of the alphanumeric character produced by a minifying -10 D lens positioned anterior to the monitor. The monitor and minifying lens were mounted on a moveable platform to allow for precise movement of the image within the optical system. The subject maintained the identical position as above, i.e., 20 cm anterior to the +5 D Badal lens.

Contrast Sensitivity. A Tektronix 608 (P31 phosphor) high resolution monitor and a Picasso digital image generator were used to generate grating patterns for contrast sensitivity testing. The image generator was controlled by an appropriately interfaced microcomputer (Apple IIe). The microcomputer timed stimulus presentation, produced auditory prompts, and recorded the subject's responses. The face of the monitor was surrounded by a large, white screen that obscured the visibility of contours in the subject's peripheral visual field. Subjects viewed the display monocularly from a distance of 57 cm in a dimly lit room. A chinrest was used to stabilize head position.

Procedure

General Procedure. In order that complete accommodative data might be obtained for both eyes, each eye was tested separately. Therefore, two sessions were run for each subject. At the start of the first session subjects were given a verbal description of the task and then asked to sign a consent form. Hue discrimination, using the Farnsworth 20-hue test, visual acuity and accommodative range were then assessed. Next, the subject was positioned in the optical system and given specific verbal instructions regarding the resting position (RP) and sustained detection tasks. Three measures of resting position were obtained. Following this, an initial block of the sustained detection test was conducted, an additional three measures of RP were assessed, another block of the sustained detection task was conducted, and a final three measures of resting position were obtained. A photograph of the pupil was then taken. Lastly, a contrast sensitivity function was determined. Rest periods were taken at the subject's request. All tasks were monocular and only one eye was assessed per session.

Accommodative Range. Both near point and far point were measured by stepping the target from the point of sharp focus and then reversing direction until a point of blur was noted. Each near and far measure was taken three times.

Resting Position. Subjects were asked to flash the pattern at irregular intervals. After using as many flashes as necessary, subjects were then asked to identify the perceived direction of motion of the laser "speckles", indicating whether they appeared to be moving either upward or downward. The drum was then moved to a new position on the optical bench. Using a bracketing technique the drum was first positioned at extreme near and far optical distances and moved inward over successive presentations. This "bracket interval" was gradually reduced until a point of no apparent motion was found. In this manner nine resting positions of accommodation were assessed over the course of the session.

Sustained Detection. Each trial began with a short auditory tone followed by the immediate presentation of an alphanumeric stimulus. At a randomly determined interval (2 to 10 sec) after the onset of the stimulus the character was subtly changed into the other alphanumeric character. Subjects held a game paddle and were instructed to depress the button if the stimuli were a 3 and to release the button if the stimuli were an E. The subject's task was to fixate on the stimulus and to press the button as soon as a character change was detected. After a two-second interval an auditory tone cued a button press if the subject failed to detect the stimulus change. Ten two minute trials were divided into two blocks. Each trial was conducted so that the monitor was placed at one of five optical viewing distances.(0.00, 1.00, 1.60. 2.50, or 3.98 D). Viewing distance was tested on one descending block and one ascending block. If the subject had maintained accurate accommodation on the stimulus, reaction times were expected to be short. If however, accommodative control became fatigued and drifted from the stimulus location, reaction times were expected to be long.

Contrast Sensitivity. Contrast sensitivity was measured using a computer-automated method of limits. The start and subsequent presentation of threshold trials were triggered by the subject who was tested under self-paced conditions. Following an auditory tone, a mid-contrast test grating was flashed onto the rectangular face of the monitor. The test grating was used to reduce stimulus uncertainty by informing the subject of the spatial frequency for the next stimulus block. Six spatial frequencies (10.0, 7.0, 5.0, 3.0, 1.0, 0.5 c/deg) were tested in two blocks of three. Blocks were tested in a randomized order. The initial start value was set at zero contrast and was automatically increased at a constant rate. In the subsequent threshold trials subjects were instructed to depress a button as soon as they could just detect the grating. Testing was performed with ambient room light and natural pupils. Monocular contrast functions were obtained by total occlusion of the fellow eye.

Results

Accommodative Range

Accommodative range was assessed by a two-factor repeated measures analyses of variance (ANOVA) in which group (i.e. MS patients or control subjects) served as the between variable and near point/far point served as the within variables. The results reveal that MS patients do not differ from age-matched controls on any of the measures. As shown in Figure 3, this analysis indicates that MS patients do not differ from controls in near point, far point or accommodative range. The average range of accommodation across all subjects was 10.3 diopters (D), the average near point was 10.2 D and the average far point was -0.14 D.

Individual accommodative data are summarized in Table 2.

Accommodative Resting Position

Figure 4 depicts mean resting position, as measured by the laser, for both groups. The resting position measures obtained in the experiment varied over a relatively large range, from 0.00 D to 3.84 D with a mean of 2.16 D. Variability for the nine laser measures of resting position obtained during an individual test session was relatively low (mean = 0.15 D) and did not differ by group. In fact, Ward and Charman (1985) report that the precision of the bracketing technique used for resting position of accommodation measures is typically about 0.15 D.

Several researchers (Maddock, Millidot, Leat & Johnson, 1981; Simonelli, 1983; McBrien & Millodot, 1987) have reported that some refractive error groups (i.e., myopes) demonstrate resting positions closer to far point than other refractive error groups (i.e. emmotropes or hyperopes). To evaluate the possibility of neurological groups differing on

Table 2.

Individual Accommodative Data.

	Age	Acuity	Near Pt	Far Pt	Range	Rest Pos
Controls						
1	23.3	20/20	12.71	0.00	12.71	3.84
2	23.3	20/20	11.77	0.00	11.77	3.84
3	32.5	20/15	11.59	0.00	11.59	1.96
4	32.5	20/15	13.77	0.00	13.77	1.89
5	35.0	20/20	5.92	-0.90	5.02	0.00
6	30.8	20/30	7.69	-0.44	7.25	0.19
7	27.3	20/20	12.05	0.00	12.05	1.58
8	27.3	20/15	13.54	0.00	13.54	1.61
9	30.5	20/20	8.62	0.00	8.62	1.88
10	30.5	20/15	7.87	0.00	7.87	1.41
11	33.5	20/15	12.11	0.00	12.11	3.06
12	33.5	20/15	9.98	0.00	9.98	1.66
13	28.5	20/15	11.56	-.71	10.85	2.94
14	28.5	20/20	9.04	0.00	9.04	2.78
MS Patients						
1	31.00	20/20	10.52	0.00	10.52	0.83
2	31.00	20/20	8.04	0.00	8.04	1.13
3	33.3	20/30	13.89	0.00	13.89	2.00
4	32.0	20/40	6.57	0.00	6.57	1.38
5	33.5	20/50	12.50	-.70	11.80	----
6	33.0	20/15	10.86	0.00	10.86	2.74
7	33.0	20/30	7.34	-1.33	6.01	2.50
8	26.5	20/30	13.71	0.00	13.71	3.59
9	27.9	20/30	11.63	0.00	11.63	0.78
10	27.9	20/40	8.70	0.00	8.70	----
11	31.1	20/20	9.84	-.10	9.74	3.38
12	31.1	20/30	11.64	0.00	11.64	3.33
13	23.7	20/15	8.13	0.00	8.13	2.32
14	23.7	20/20	9.04	0.00	9.04	3.64

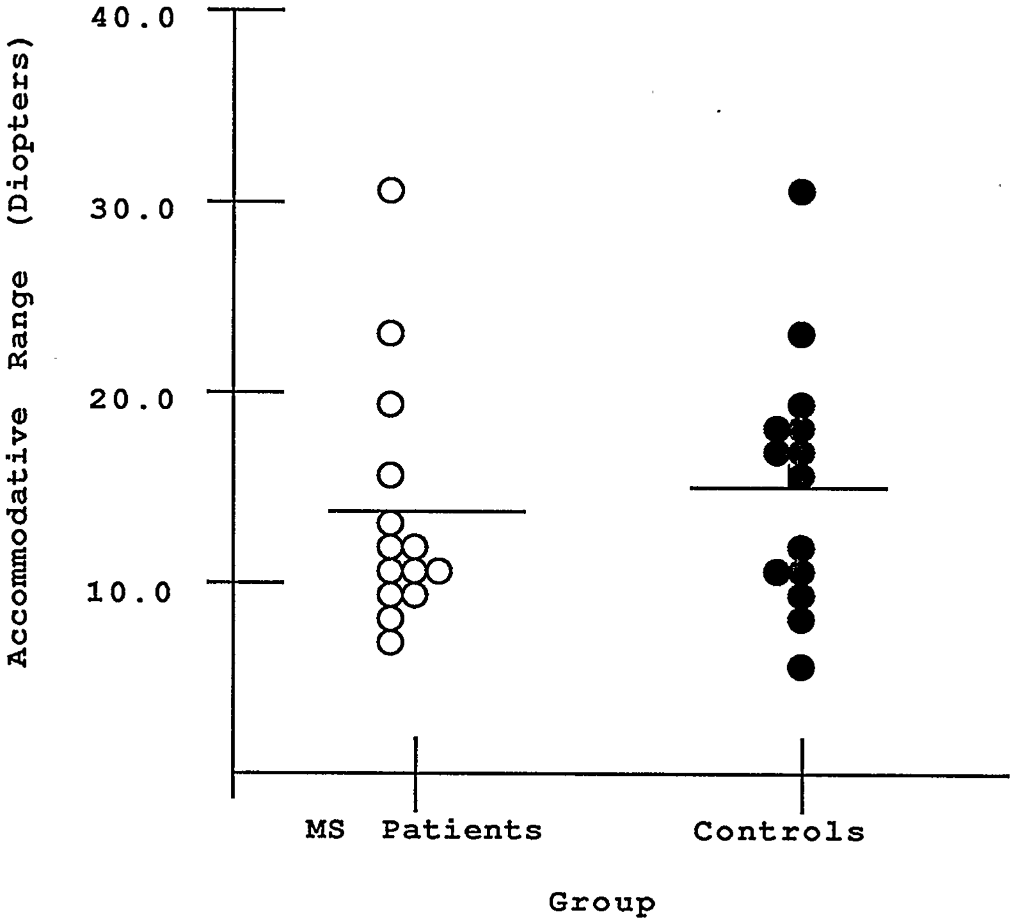

Figure 3. Individual accommodative range measures for both the multiple sclerosis and control groups. The horizontal lines represent the group means.

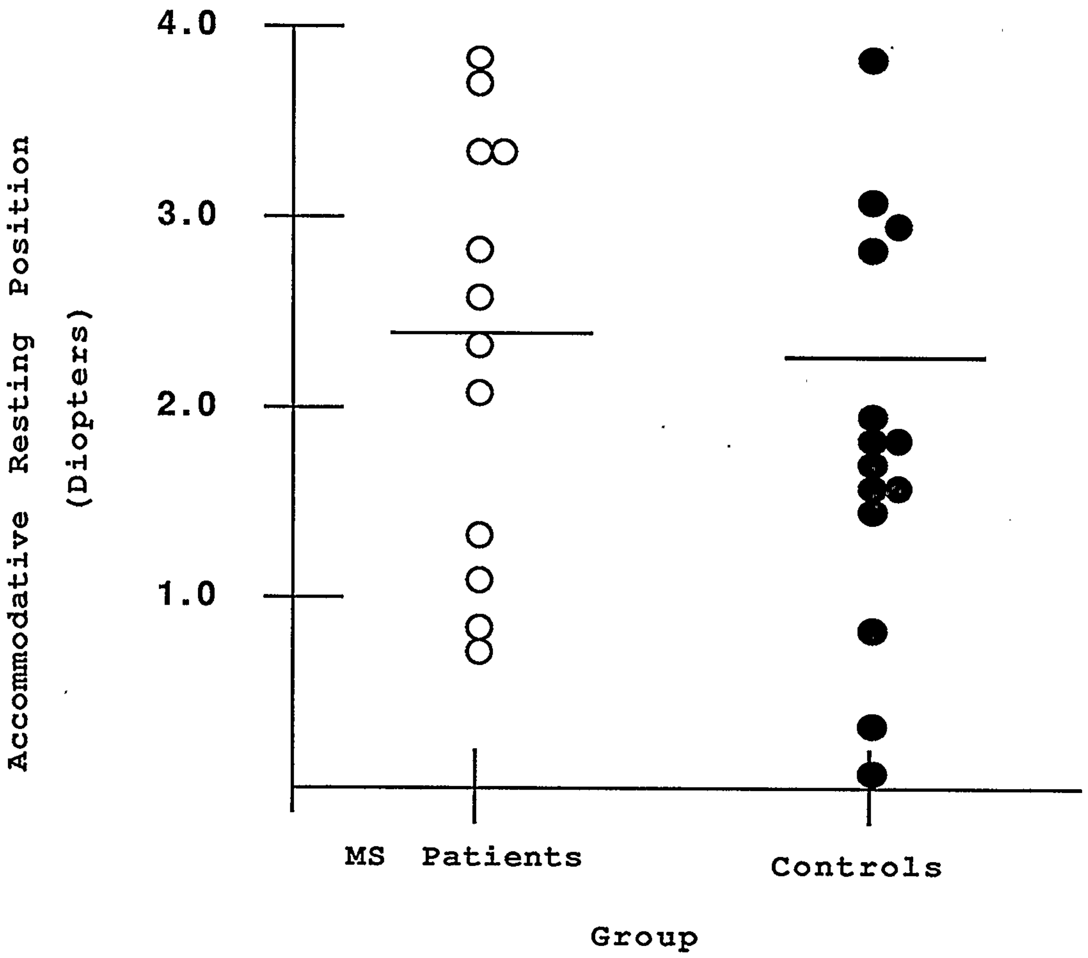

Figure 4. Resting position of accommodation as measured with the laser optometer for individual subjects. The horizontal lines represent the group means.

this measure, distribution of resting position from far point was analyzed. A one-way ANOVA, assessing dioptric distance between far point and resting position for both groups revealed no significant differences between groups.

Direct and Indirect Measures of Resting Position. In the sustained detection psychophysical task, reaction time (RT) varied as a function of optical stimulus distance. For all of the 28 eyes tested, RT reached a minima at an individually determined viewing distance. The viewing distance at which RT was lowest was taken to represent the individual's resting position of accommodation. This assumption was based on a previous experiment by Raymond & Leibowitz (1985) where sustained detection of a grating pattern was found to be maximal at a viewing distance corresponding to the resting position of accommodation.

This assumption was validated in the present study using the following analysis. A repeated measures ANOVA was conducted to evaluate differences in resting position between groups and to evaluate differences in the two methods for assessing resting position; i.e., directly using the laser optometer or indirectly using the psychophysical method described above. No significant main effects or interactions were revealed, indicating that the psychophysical method provides a reasonable estimate of resting position as directly measured by the laser. Moreover,resting positions of MS patients do not differ significantly from control subjects.

Sustained Detection Task

Mean RT to detect a change in an alphanumeric character for each optical stimulus distance tested was calculated for each subject, for each optical distance. Mean RT varied as a function of optical stimulus distance revealing a minimum, at about 1.5 D for both groups, and rising on either side of this point. As shown in Figure 5, the group mean RT's show that MS patients consistently responded for all viewing distances with longer RTs than control subjects. The slopes of both curves indicate that both groups demonstrated attenuated performance at very close and very far distances. As hypothesized, a repeated measures ANOVA on the RT data of both groups showed significant quadratic trends [F(1,23)=43.45, p<.0001]. Moreover, a significant effect of group was noted [F(1,23)=8.68, p<.01] and a significant group by quadratic interaction emerged [F(1,23)=6.78, p<.025]. Thus the analysis indicates that, compared to age-matched controls, MS patients respond with elevated RT to all optical stimulus distances. Second, MS patients' performances are more greatly attenuated than controls for extreme near and far optical stimulus viewing distances. These results indicate that as a group MS patients demonstrate an impoverished ability to sustain detection at *any* viewing distance compared to age-matched controls. However, it is interesting to note that at optical infinity even control subjects require over 1 sec to respond to a stimulus change.

In order to more directly assess the effect of accommodative effort on sustained detection, RT was examined as a function of optical distance *relative* to the resting position of accommodation. This was done by assigning a relative optical stimulus distance value of zero to the optical stimulus distance which produced each individual's RT minimum (resting position). This normalizing approach permits comparison of RT at uniform increments of near and far viewing distances on either side of resting position. The results were therefore averaged by normalizing for the function of the mathematical minimum.

To obtain a mean RT for each relative optical stimulus distance, a minimum of three subject's data were used. This eliminated the two extreme relative optical distances (3.98 D

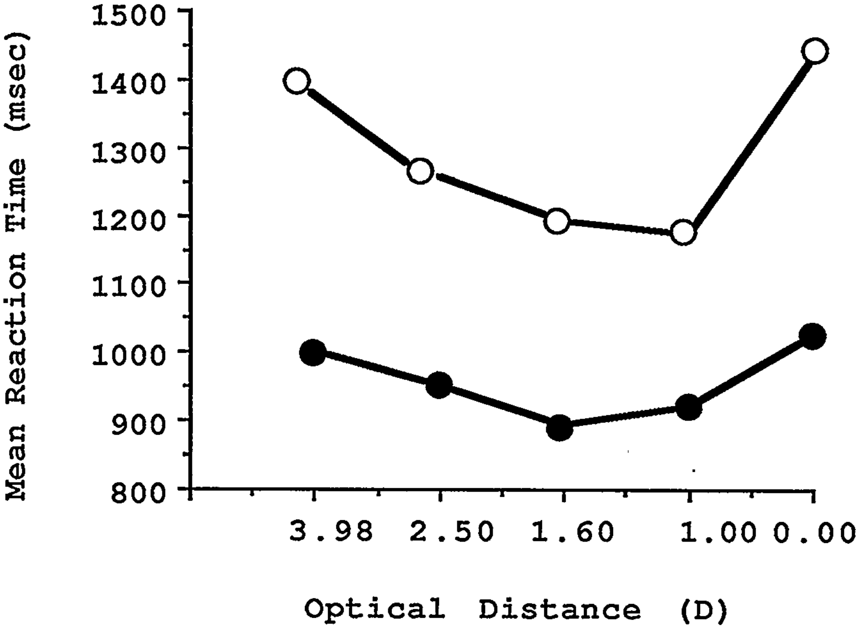

Figure 5. Reaction time to determine the character change as a functior of the optical distance of the stimulus. The solid circles represent RI for control subjects. The open circles represent RT for the MS patients

near and -3.98 D far) from all analyses using normalized data. This indicates that in both groups less than three eyes had resting positions at either of the extreme distances (i.e. 0.00 D and 3.98 D).

The resulting group mean curves are shown in Figure 6. Here again, large differences in RT for all viewing distances between groups is evident. The mean magnitude of the difference between MS and control RT across viewing distance is 355 msec. The mean RT rose from a low value of 1095 msec, to a high value of 1717 msec as the difference between the viewing distance and the distance corresponding to RP reached 2.50 D for MS patients. The mean RT rose from a low value of 817 msec, to a high value of 1207 msec as the difference between the viewing distance and the distance corresponding to RP reached 2.50 D for control subjects.

This consistent difference does not vary with viewing distance and may be attributed to a host of extraneous central nervous system (CNS) deficits (e.g. reduced CNS neural transmission speed, slowed motoric responding, etc.). Since CNS deficits remain constant across viewing distance and changes from one viewing distance to another can be attributed to accommodative change only, difference scores were generated from the normalized curve by subtracting the RT obtained at the resting position from that obtained at a given relative optical stimulus distance.

A repeated measures ANOVA was employed to analyze difference score data. Group was the between subject variable and the five optical stimulus viewing distances served as the within variables. As expected, group differences were nonsignificant when using difference scores. This suggests that the significant group effect obtained using raw data is largely due to the substantial differences in reaction time between the two groups. However, the significant group x quadratic effect remains

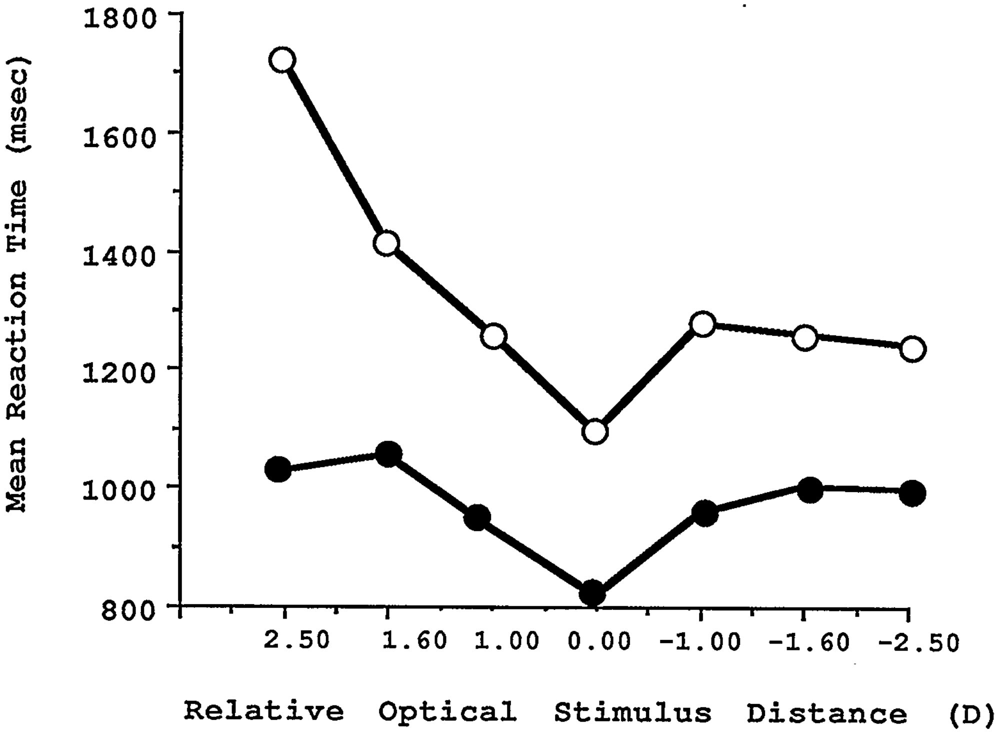

Figure 6. Group mean RT plotted as a function of optical distance relative to the distance corresponding to the RT minima (RP). Closed circles represent control subject data. Open circles represent MS patient data. Positive D values indicate distances closer than RP and negative D values indicate farther optical distances.

[F(1,23)=6.78, p<.025]. As shown in Figure 7, this indicates that the groups differ in their response profiles to relative optical stimulus distance in spite of controlling for overall reaction time.

To assess group differences in the rate of increase in RT, with increasing relative optical stimulus distance for viewing distances both nearer to and farther away from RP, each individual's near slope and far slope was calculated. Using a multiple regression approach, differences in far slope for MS patients and control subjects were determined to be nonsignificant. However, differences between groups at near slope were significant [F(1,26)=5.37, p<.05], suggesting that MS patients are less efficient outside of resting postion at near distances than age-matched controls.

Variability of Response

Another characteristic of the data is that the variance in each subject's RT score also changed as a function of viewing distance. A trend analysis evaluating standard deviations (SD) of RT at the five optical stimulus distances indicated significant main effects of group [F(1,23)=14.96, p<.001] and viewing distance [F(1,23)=11.39, p,.01] and a significant group by quadratic interaction [F(1,23)=7.56, p<.01]. As shown in Figure 8 both groups demonstrated a decremented performance at the extreme near and far viewing distances. However, MS patients showed greater variability of response at all viewing distances.

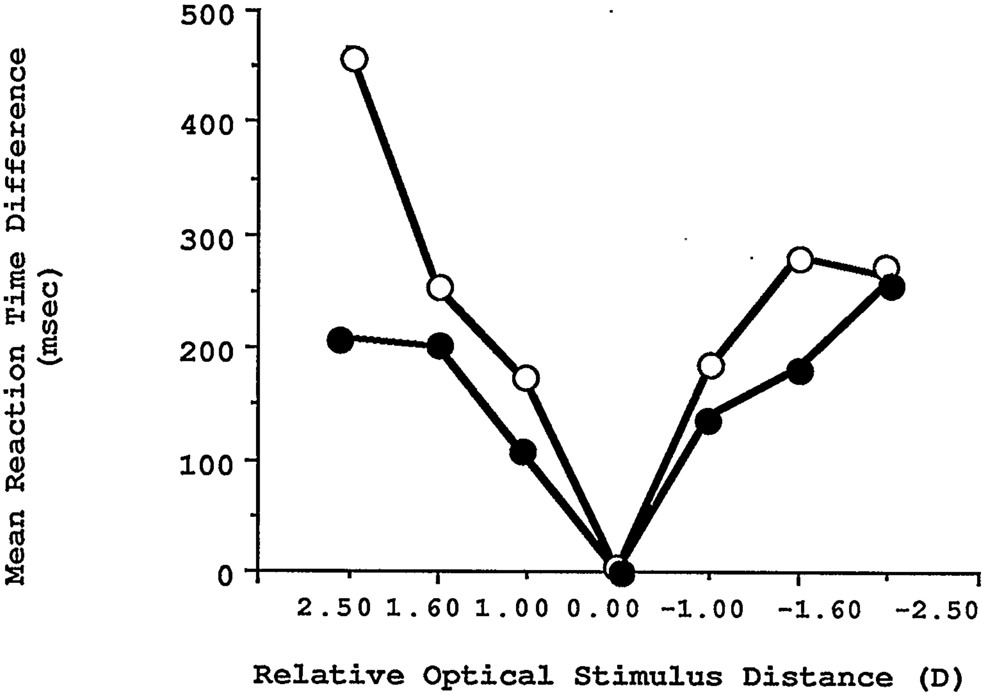

Figure 7. Group difference mean RT plotted as a function of optical distance relative to the distance corresponding to the RT minima (RP). Closed circles represent control subject data. Open circles represent MS patient data. Positive D values indicate distances closer than RP and negative D values indicate farther optical distances.

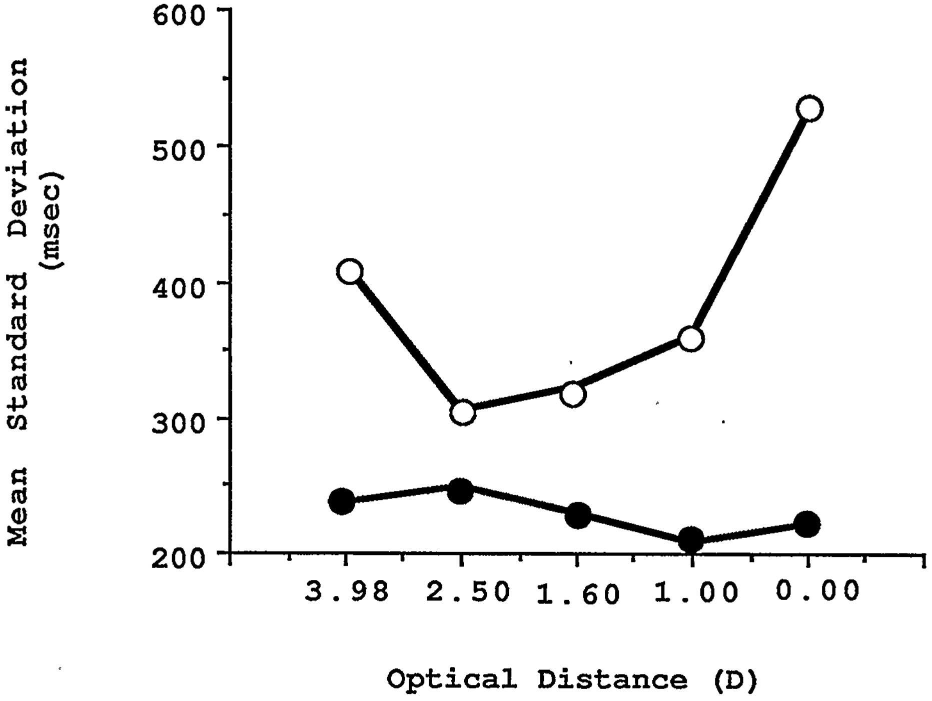

Figure 8. Standard deviation in reaction time to detect the symbol change as a function of the optical distance of the stimulus. Closed circles represent control subject data and open circles represent MS patient data.

The data were then normalized with individual subject's RT measured as a function of the optical stimulus distance relative to resting position. As shown in Figure 9, for the viewing distance that produced the lowest RT, the average standard deviation was also relatively low (165 msec, 68.6 S.D.) for the control group but was elevated for MS patients (265 msec, 149.8 S.D.). A two-factor mixed-design ANOVA revealed a significant effect of group [F(1,21)=7.71, p<.01] and a significant effect of viewing distance [F (2,21)=15.83, p<.0001] but no significant interaction. This suggests that both groups show greater variability outside of resting position but that MS patients show greater variability than age-matched controls at all viewing distances, including resting position.

Each individual's variance data were normalized then examined for slope on either side of the minima; that is, slope was analyzed for both distances nearer to resting position and distances farther away from resting position. A two factor mixed design ANOVA was conducted to evaluate rate of change outside of resting position between groups. The analysis approached significance for a main effect of group [F(1,16)=3.28, p<.09]. Multiple sclerosis patients appear to be inconsistent at all viewing distances. This response variability has been noted in a variety of other visual tasks (Patterson,Foster & Heron,1980) and has been attributed to Troxler fading in MS. However, this unique effect of visual fatigue remains constant across optical stimulus viewing distance and cannot account for increases in variability outside of resting position.

Error Scores

The number of false alarms (responding to a perceived stimulus change in the absence of an actual stimulus change) and misses (failure to detect an actual stimulus change) were

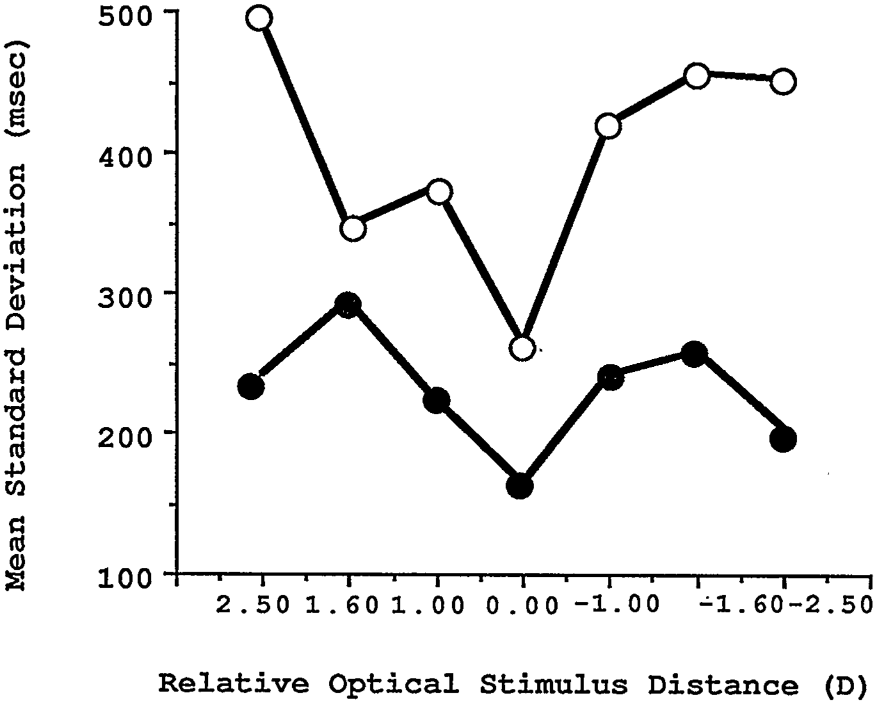

Figure 9. The group mean standard deviations of RT for each group as a function of optical distance relative to resting position. Open circles represent MS patients and closed circles represent control subjects. Positive D values represent optical distances closer than RP; negative values represent farther optical distances.

calculated for each individual at every viewing distance. A trend analysis revealed a significant group effect [F(1,22)=29.24, p<.0001] but no other effects or interactions were significant. Each error type analyzed separately yielded similar analyses. As shown in Figure 10, although MS patients made significantly more errors at all viewing distances,there was no interaction between viewing distance and group.

The error data were then normalized relative to resting position and a mixed-design ANOVA was used to analyze group as a between variable and viewing distance as a within variable. Again, a significant effect of group was revealed [F(1,20)=8.07, p<.01]. As shown in Figure 11, the age-matched controls' mean error at resting position was 0.6 whereas MS patients mean error at resting position was 5.3.

Cycloplegic Condition

To ascertain whether the increases in RT to the change in the alphanumeric stimulus as a function of viewing distance resulted from a change in accommodative control, a cycloplegic (Cyclopenyolate hydrochloride; 1% solution) was introduced into the eye of one control subject. Accommodative range, resting position and ability to sustain detection were then assessed. It was found that accommodative range was reduced to 1 D. However, resting position was virtually identical to the resting position measured in the uncyclopleged eye (1.3 D cyclopleged versus 1.4 D uncyclopleged) with a reduction in variability (S.D.=0.14 D cyclopleged versus S.D.=0.23 D uncyclopleged).

In the sustained detection task it was found that within a limited range the alphanumeric character was either visible for the entire interval or not detectable at all. Three stimulus distances (0.00 D, 0.63 D, 1.00 D) farther than the resting position were detectable with the greatest efficiency

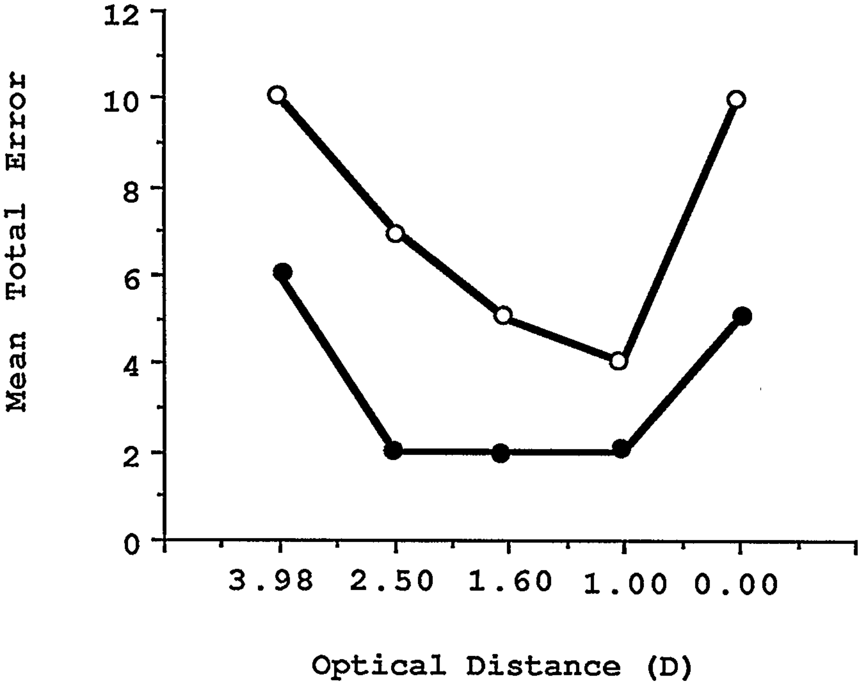

Figure 10. Mean error measured for each group as a function of optica stimulus distance. Open circles represent MS patients' data; closed circles represent control subjects' data.

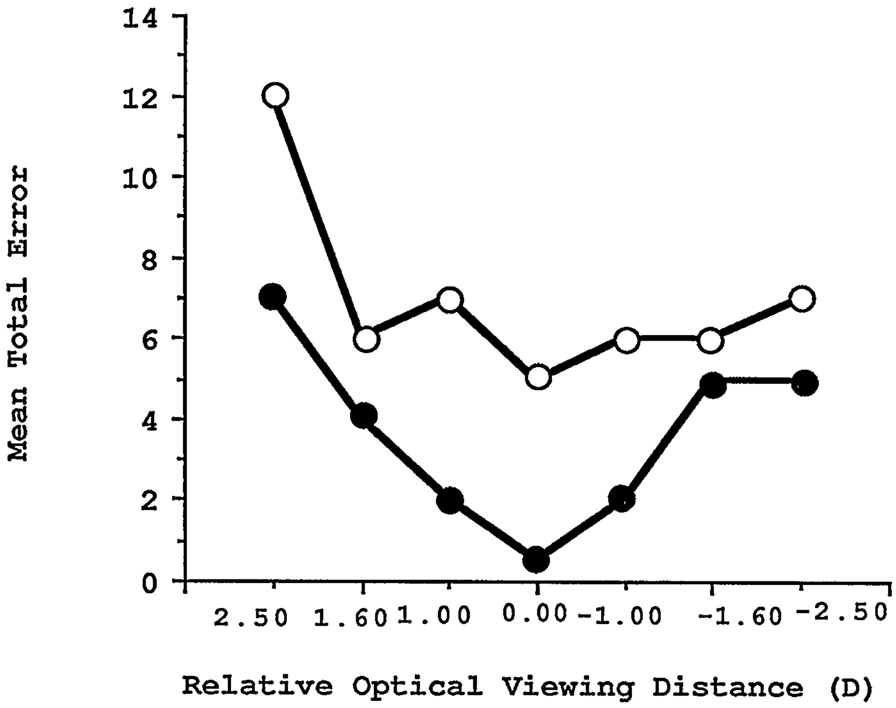

Figure 11. Mean total error scores measured for each group as a function of the optical distance relative to the distance corresponding to the RT minima (RP). Open circles represent MS patients' data. Open circles represent control subjects' data. Positive D values indicate an optical distance closer than the distance corresponding to the RP; negative values indicate a further optical distance.

at 0.63 D. However, reaction times varied by only 100 msec from the most efficient to the least efficient viewing distance (1304 msec, 1197 msec, 1300 msec respectively). All viewing distances closer than resting position could not be focused.

Contrast Sensitivity

An analysis of the contrast sensitivity data indicated that both groups showed the expected pattern of response; that is, maximal sensitivity at mid-spatial frequencies (1 to 3 cycles/degree) with attenuated sensitivity for both lower and higher spatial frequencies. However, MS patients, as a group, demonstrated a significant reduction in sensitivity to all spatial frequencies (mean log threshold difference = 0.230). At all extreme spatial frequencies MS patients required nearly double the amount of contrast to detect the grating pattern.

The data indicated that half to three-quarters of the MS patients fell outside of the 99% confidence interval for high (10/14) and low (7/14) spatial frequencies. Mid-spatial frequency contrast thresholds were not significantly different from age-matched controls.

More specifically, only four control eyes demonstrated decrements in contrast sensitivity that fell outside of the 99% confidence interval. Low, medium and high spatial frequency loss were evenly distributed. Only one of the four eyes demonstrated a corresponding abnormal accommodative response - falling outside of the 99% confidence interval for all relative viewing distances. Resting position distribution and accommodative range were unrelated to spatial contrast deficits.

However, all fourteen MS eyes demonstrated a contrast sensitivity loss that fell outside of the 99% confidence interval at at least one spatial frequency. Three eyes showed a generalized loss of contrast, two eyes showed a low frequency loss and four eyes showed a loss at both high and low spatial frequencies, but normal response at mid-spatial frequency. All three loss types were characterized by scattered abnormal accommodative response across relative viewing distance. One eye demonstrated a mid-frequency loss and was characterized by a generally normal accommodative response across all relative viewing distances. Four eyes showed a high spatial frequency loss and were characterized by abnormal accommodative responses to viewing distances immediately closer to, or farther from, resting position. Resting position distribution and accommodative range were unrelated to spatial contrast deficits.

Individual Data

The above data clearly demonstrate that MS patients, as a group, exhibit sustained detection decrements in comparison to age-matched controls. However, Figure 12 more clearly demonstrates the wide variations that exist between MS patients. In particular it is striking to note that most MS patients show substantial increases in reaction time at near distances. For example, at 2.50 D near point 5/5 MS patients were outside the 99% confidence intervals established by control data. No control subjects fell outside of these limits. However, at far point this difference between groups is less evident; 2/4 MS patients and 1/5 controls exhibit decremented performance outside of the 99% confidence limits. It is also notable that some MS patients, at some relative viewing distances are more efficient than controls.

Two subjects were taking Ditropan (oxybutynin chloride) for urinary tract complications. Both subjects demonstrated normal mid-frequency response but were impaired at both the low and high spatial frequencies. A corresponding abnormal accommodative response occurred across most relative viewing distances.

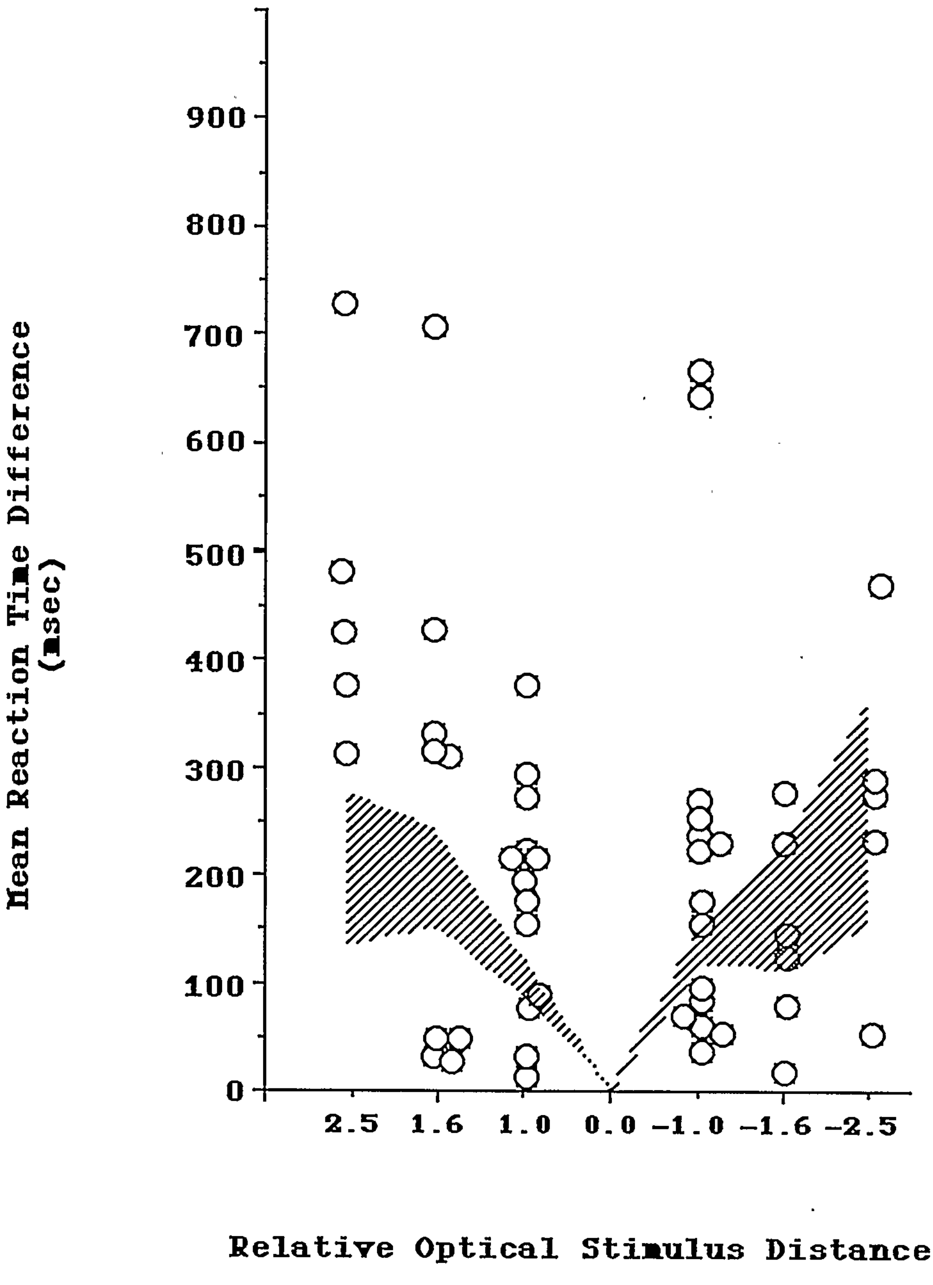

Figure 12. Individual group difference data plotted as a function of relative optical stimulus distance. The hatched area represents the 99% confidence limits for the control group. The open circles represent MS patient data.

Discussion

One of the main purposes of the study was to examine the effect of optical stimulus distance on sustained detection. The assumption was that changes in optical stimulus distance relative to resting position would produce changes in accommodative effort. Moreover, it was expected that, due to the fatigue on exertion that is associated with this disease, MS patients would have greater difficulty sustaining detection than age-matched controls. In fact, this study indicates that a strong accommodative effect does exist in the sustained detection task (as verified in the cycloplegic condition) and further indicates that MS patients experience difficulty when a sustained accommodative response is required.

Therefore, the hypotheses of the study were generally confirmed. Speculations for minor deviations from what was expected and what was observed will be suggested. This will be followed by a discussion of the implications of the data and their application to MS.

When the slopes, analyzing rate of performance attenuation outside of resting position on both the near and far side, are analyzed for each group only a difference at near viewing distance (distances closer than resting position) was found. These data suggest that near viewing for an MS patient may cause added stress to the accommodative system which may result in degraded perception. This data is supported by an observation that MS patients, as a group, avoid near tasks and prefer to spend their time at more intermediate to far tasks. Fleishman, Beck, Linares and Klein (1987) confirm that MS patients report a preference for watching television or going for drives to reading.

The present data indicate that MS patients, as a group, are able to sustain detection to objects farther than their resting position as well as age-matched controls. Therefore, MS patients would not demonstrate performance attenuation at skills requiring sustained accommodation for viewing distances farther out than resting position (e.g. driving). However, as will be discussed further, gross differences in reaction time measures should warrant consideration for applied tasks.

As hypothesized in the sustained detection task, all subjects' reaction times to detect the change in the alphanumeric stimulus were lowest at an idiosyncratic optical distance and rose as the difference between the viewing distance and this point increased, for both near and far optical distances. A statistical analysis comparing the measures obtained by the sustained detection measure and the laser optometer measure revealed no significant differences, indicating that the sustained detection task generates a reasonable estimate of resting position. Therefore, this research validates Raymond's (1986) assumption that the minima corresponds to the resting position of accommodation.

As suggested by Raymond (1986) the computer-generated character used in the display was a poor accommodative stimulus and hence probably produced low-frequency drifts of accommodation similiar to those reported by Johnson, Post and Tsuetaki (1984). Due to the degraded stimulus conditions of the task, at viewing distances outside of resting position, accommodation was expected to be in a constant state of high-amplitude drift (Campbell, Robson & Westheimer, 1959). On some trials accommodation could be coincidentally accurate at the time of the letter change, resulting in greater variability. This was corroborated by variability data and error scores. For both groups the standard deviation of the RT measure varied as a function of the optical stimulus viewing distance relative to resting position.

Both groups demonstrated higher variability outside of resting position. However, MS patients' showed greater decrements in performance at all relative viewing distances, indicating greater accommodative flucuation during the sustained detection task than age-matched controls. Even at resting position MS patients were generally less efficient at sustaining detection; they demonstrated large flucuations in accommodative response and made numerous errors.

Results indicate that MS patients respond with elevated RT to all relative optical stimulus distances compared to healthy age-matched controls. MS patients' performances are more attenuated as a function of relative optical stimulus distance than controls, indicating that as a group MS patients demonstrate an impoverished ability to sustain detection at *any* viewing distance. It is worth noting that, for MS patients, the gross differences in RT between controls and multiple sclerosis patients were in the order of 300 or 400 msec. This inability to react to a change in a visual stimulus outside of resting position without this additional amount of time is important from a practical standpoint. Resting positions are equally distributed across all viewing distances for each group so this does not account for the significant difference between groups.

A small difference in acuity was found between groups. Control subjects have a mean Snellen acuity of 20/20 and MS patients have a mean Snellen acuity of 20/30. However, the alphanumeric character used in the sustained detection task was 20/70 and thus it seems improbable that the differences in sustained detection are due to differences in visual acuity. Rather, it is feasible to attribute differences between groups in sustained detection to accommodative fatigue.

MS patients did not differ significantly from age-matched controls in accommodative function, on traditional measures of accommodative function (i.e., range and resting position). Although there is a paucity of detailed research on MS and accommodative function, one report on the subject described the acuity and range of one MS patient (Gutteridge, 1985). It was reported that one patient suffered severe attenuation of accommodative range (4 D) during an attack. Following "recovery" it was reported that acuity and range had returned to normal. From this optometric viewpoint there are no residual significant abnormalities in accommodative function associated with MS.

This may, in part, account for the MS patient's complaint of transient blurring of vision in spite of normal or near-normal visual acuity. Sustaining an accommodative response is effortful and abnormal fatigue on exertion is characteristic of MS. Therefore, it seems plausible that MS patients have an impaired capacity to sustain an accommodative response.

Patients with high spatial frequency losses should have greater difficulty responding to blur and are therefore more likely to experience difficulty when attempting to stabilize the accommodative response. This is verified by the data. Only patients with high frequency losses experienced difficulty sustaining an accommodative response immediately outside of resting position.

Changes in sustained detection could be attributed to indirect results of changes in vergence. If the two systems were directly related one would expect to see a significant positive correlation between the two measures of resting position and dark vergence. However, Owens and Leibowitz (1976) found that the synkinesis between accommodation and vergence breaks down in darkness. Furthermore, Miller (1988) measured resting position and dark vergence under a variety of conditions and reports that the two measures are not significantly correlated. This suggests that the required accommodative effort required for the monocular, sustained detection task was unaffected by vergence.

Ward (1987) found that the accommodative response on the near side of resting position was not influenced by contrast, whereas it did appear to affect far. Additionally, Romano and Stark (1973) report that blurring of near vision is a frequently associated symptom of myasthenia gravis but that blurring of distant vision is rare. This suggests that the systems for viewing near and far are separately innervated.

It is widely accepted that the ciliary muscles, responsible for accommodation, are autonomically innervated, although the roles of the parasympathetic and sympathetic divisions are still debated (Ward, 1987). The classical theory of accommodation assumes that the only active process of accommodation is an increase in the refractive power of the eye, produced by contraction of the ciliary muscle (Alpern, 1969). This theory proposes that only parasympathetic innervation to the ciliary muscle is important in active accommodation. When this parasympatheic system is activated, an increase in refractive power is produced. When innervation ceases, relaxation of the ciliary muscle occurs, and the refractive power of the eye is decreased. Hence, when the parasympathetic innervation is at tonic level, the ciliary muscle is assumed to be relaxed and the eye is focused at its far point.

Although the concept of resting position at optical infinity has been accepted widely since it was first proposed by Helmholtz (1909), it has, in recent times, been shown to be inaccurate. It is now well established that the eye adopts an intermediate resting position in the absence of visual stimulation (Leibowitz & Owens; 1975). Toates (1972) states that the resting position of accommodation is determined by the equilibrium established between sympathetic and parasympathetic tone; according to this model, accommodation for distant objects is actively induced by the sympathetic system, and the parasympathetic division produces accommodation for near objects.

A great deal of behavioral evidence supports the notion of dual innervation. For example, psychological stress shifts the dark focus to a nearer position (Miller, 1978) while severe cardiovascular stress produces a shift in the far direction (Leibowitz, 1976). Both pharmacologic and anatomic investigations have demonstrated the presence of a sympathetic innervation to primate and human ciliary muscle

(Tornqvist, 1967; Hurwitz, 1972). They suggest that this effect is inhibitory in nature.

To reiterate, Toates' model proposes that increased sympathetic activity is responsible for adjusting ocular focus for distant vision, and parasympathetic activity is required for near vision. This would require sympathetic-mediated distance accommodation to be as rapid as parasympathetic-mediated near accommodation (Ward, 1987). This, however, is in conflict with the observations of Tornquist (1967). He found a sympathetic-mediated negative accommodation increase in effect when the underlying level of parasympathetic activity was increased. From this finding he concluded that sympathetic stimulation to the ciliary muscle was inhibitory in nature.

However, two patients taking sympathetic blocking drugs failed to show an enhanced near response effect, as might be expected if parasympathetic response were uninhibited. This may be due to a host of extraneous variables or the small sample; however, the data certainly suggest that any generalizations about parasympathetic responding are speculative.

Although resting position is subject to change (Ebenholtz, 1983; Baker, Brown & Garner, 1983; Tan & O'Leary, 1986) under normal conditions of visual stimulation it is relatively stable over the short term (Miller, 1978; Mershon & Amerson, 1980; Tan & O'Leary, 1986). This generally consistent nature of resting position argues for its usefulness in predicting and optimizing visual performance.

For example, night myopia is a low luminance condition that is associated with degradation of retinal image clarity. Emmetropic subjects often become myopic under these conditions. However, Leibowitz and Owens (1976, 1977) have demonstrated that this is correctable through the use of negative ophthalmic lenses. Leibowitz, Post, Brandt and Dichgans (1982) found that roughly one-half of the resting position value is a good approximate of the necessary correction to increase image clarity at night.

Thus, if MS patients experience unusually rapid fatigue of accommodation, visual fatigue can be ameliorated by optical adjustment of the resting position to the individual's most commonly used viewing distance. The present data suggests that it would be particularly reparatory to correct MS patients for near viewing distances. However, further research with this patient population may be necessary in order to determine whether resting position is a stable accommodative characteristic within this group.

These data also suggest that careful attention to dioptric factors should be considered before conclusions regarding neural loss are made. Contrast sensitivity, measuring the detectability of low contrast sine wave gratings, is abnormal in a large proportion of MS patients. Although MS patients have been shown to exhibit losses in spatial vision, attribution of contrast sensitivity loss to central neural pathology may be unwarranted in some cases. For example, Apkarian, Tijssen, Spekreijse and Regan (1987) indicate that medium spatial frequency losses in contrast sensitivity may be attributable to astigmatic factors.

Raymond, Lindblad and Leibowitz (1984) demonstrated that grating patterns are poor stimuli for accommodation.. Furthermore, Lindblad, Raymond,Leibowitz and MacDuffee (1983) found that as dioptric differences between the individual resting position and stimulus distance increased, contrast sensitivity was reduced. Although accommodation is generally a compromise between an individual's resting position distance and the stimulus distance, the degree of accommodative inaccuracy depends on the effectiveness of the stimuli in evoking a focusing response. These data suggest that viewing distances outside of resting position are associated with corresponding increases in accommodative inaccuracies.

Moreover, Medijbeur and Tulunay-Keesey (1986) report data that suggest that an accommodative basis for contrast sensitiviy losses may exist. They found that, although MS patients showed abnormal responses to threshold stimuli their perception of suprathreshold stimuli was normal. Raymond, Lindblad and Leibowitz (1984) have also demonstrated that increasing the contrast in a grating pattern serves to improve its effectiveness as an accommodative stimulus. These data suggest that some MS patients may be unable to accommodate to threshold grating patterns outside of resting position and, hence, may appear to exhibit a neural loss when, in fact, it is a dioptric deficit. In order to explore this more fully contrast sensitivity would have to be assessed as a function of viewing distance, with and without cycloplegia.

Different visual tasks afford unique combinations of stimuli, and the accommodative system must be able to respond adequately under all circumstances. By having a variety of cues that it responds to, accommodation is able to function efficiently under diverse viewing conditions. Therefore, the arrangement of the natural environment and the optical transformations that occur in the eye itself, present the accommodation system with an array of redundant information. The system may well have adapted to use this information in order to respond effectively under diverse viewing conditions. This may, in part, explain the diversity of perceptual deficits associated with MS; functional adaptation to demyelination in the visual system will vary from one patient to another. The MS patients tested for this study report very few visual discrepancies in spite of data that suggest that many of them are perceptually incapacitated.

This research has clearly demonstrated that dioptric factors are an exigent aspect of visual abnormality in the MS patient. This research should be extended to include a variety of variables (e.g. luminance, temporal factors etc.)

to assess their import on accommodative function in the MS patient.

Although the majority of past research has centered on diagnostics and is recognized as valuable, the importance of describing the changing visual world to a patient cannot be undermined. Beginning to characterize the visual world of the multiple sclerosis patient is an important goal of this research. Patients do not passively perceive a static world but focus actively on stimuli viewed at a number of different planes in depth. Measures like contrast sensitivity are informative about the function of the visual system but may not explain the spatial visual capacity of the MS patient in a dynamic three-dimensional environment. In attempting to deal with the visual deficits which occur in a disease like MS, one must remember that human perception operates in a cultural as well as a physical environment (Bruce & Green, 1985).

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