EFFECT OF TELESCOPIC SPECTACLES ON HEAD STABILITY IN NORMAL AND LOW VISION

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Abstract — Telescopic spectacles, highly magnifying visual aids mounted in spectacle frames, markedly alter the visual consequences of head movements. To evaluate the effect of this altered visual feedback on head stability, angular head velocity of normally sighted and low vision subjects was measured in the roll, pitch, and yaw axes. Measurements were made under two postural conditions: (1) quiet standing; and (2) walking in place, as well as three visual conditions: (1) eyes closed; (2) unmagnified vision; and (3) vision with 4x binocular telescopic spectacles.

For normal subjects during quiet standing, both unmagnified vision and vision with telescopic spectacles tended to reduce spontaneous head velocity in all axes as compared to the eyes-closed condition. However, in low vision subjects neither unmagnified vision nor vision with telescopic spectacles produced significant changes in values of head velocity relative to those measured with eyes closed. Spontaneous head velocities for standing low vision subjects tended to be higher than in normal subjects, although not all differences were statistically significant.

During walking in place, Fourier analysis demonstrated prominent frequency components related to harmonics of the walking frequency under all viewing conditions. In normal subjects, vision with telescopic spectacles, to a greater degree than unmagnified vision, reduced head velocity during walking in the roll and yaw, but not the pitch, axes. For low vision subjects, significant reductions in head velocity during walking were observed only during vision with telescopic spectacles.

These findings indicate that vision reduces angular instability of the head during standing and walking.Magnification produced by telescopic spectacles further improves head stability under some conditions, although the effect of vision is least evident in the pitch axis. The stabilizing effect of vision is reduced in low vision subjects.

Keywords — head stability; low vision; telescopic spectacles; vision.

Introduction

Vision is an important input to the integrated sense of balance. It has long been known that persons wearing strong but otherwise ordinary spectacle lenses for the first time complain of disturbances of equilibrium and exhibit reduced postural stability (1). The special challenges to equilibrium posed by very highly magnifying telescopic spectacles have previously received little or no attention. Telescopic spectacles are commonly prescribed as visual aids to persons having significantly impaired central visual acuity due to ocular disease (2). These low vision patients are those whose ocular diseases limit best corrected central visual acuities to 20/70 or less. Telescopic spectacles are used for a variety of tasks, principally for viewing distant objects as in educational or recreational settings (3). Some patients employ telescopic spectacles for driving automobiles (4). With the addition of supplemental convex lenses, telescopic spectacles...
may be employed for close work. While the highly magnifying devices provide remarkable rehabilitative benefit to some low vision patients (3), about one third of patients are unable to use the telescopic spectacles prescribed for them (5). It has been hypothesized that much of the rehabilitative failure with telescopic spectacles is due to the unfavorable magnification of unintended head movements (5). Head movements, present even at rest, are the ubiquitous consequence of transmitted heartbeat, tremor, ambulation, and vehicular travel (5-8). An additional component of head movement is likely to result from involuntary postural sway which constantly occurs in all human subjects (9), but is accentuated in the elderly (10). Given the minimal contribution of the cervico-colic and vestibulo-colic reflexes in absence of an active effort to stabilize gaze (11), a large amount of postural sway would be expected to be transmitted to the head. Visual deprivation (12-14) and even reductions in visual acuity (1,13) and blindness (13) increase postural sway, although the effect of poor vision on three-dimensional rotational head stability has not been previously studied.

Rotations of the head can be projected onto three orthogonal axes. Roll, pitch, and yaw represent rotations in the coronal, sagittal, and horizontal (axial) planes, respectively. The cornerstone of ocular stabilization during rotational head movements is the vestibulo-ocular reflex (VOR). Ideally, VOR gain (eye velocity divided by head velocity) would be 1.0 to perfectly stabilize retinal images of distant objects, since this means that a given angular head velocity evokes an equal eye velocity in the opposite direction. In fact, VOR gain as traditionally measured in darkness is usually slightly less than it is at frequencies below 1 Hz (15-17), but in light the VOR is enhanced by visual-vestibular interaction to increase the gain to 1.0 (16,18). The visually enhanced VOR is the visual-vestibulo-ocular reflex (VisVOR). During wearing of telescopic spectacles, maintenance of retinal image stability requires increased VisVOR gain to equal telescope magnification (19). When magnified twofold to eightfold by telescopic spectacles, unintended head movements can exceed the adaptive capabilities of the VisVOR (20), resulting in motion of images on the retina. Retinal image motion has been demonstrated to profoundly reduce the visual acuity of normal subjects (21,22). Insufficient VisVOR gain is the reason that dynamic visual acuity (DVA), the acuity during head motion, is increasingly degraded by head motion as telescopic spectacle power is increased (19). Reduced acuity during head motion might prevent the visual system from providing appropriate feedback to postural mechanisms concerning head motion, which in turn could exacerbate head instability. Alternatively, the enhancement of retinal slip by telescopic spectacles might increase the sensitivity of visual feedback signaling head movement to postural control centers. Enhanced visual feedback could improve postural stability by enabling detection of even small head movements, although excessive feedback gain could also produce reflex oscillations due to delays in visual and motor pathways. A known adverse effect of wearing telescopic spectacles during head motion is the induction of motion sickness in a substantial proportion of subjects (1,16,23). This effect may be due to visual-vestibular conflict. These observations suggest the possibility that telescopic spectacles may aggravate head instability by disruption of the visual feedback component of postural control. Consequently, the expected effect of telescopic spectacles on head stability is unclear.

The present study was thus undertaken to determine the effects of telescopic spectacles on head stability in all rotational axes and how this is influenced by the presence of low vision.

Materials and Methods

All subjects were volunteers and gave written informed consent according to a protocol approved by the Institutional Review Board for Human Research. Subjects underwent clinical eye examination by F.I.P. Eleven normally sighted subjects had corrected visual acuities of 20/20 or better in each eye. Aver-
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Average age of normal subjects was 33.4 ± 13.5 yr (mean ± standard deviation, SD; range 20–60 yr. Thirteen subjects with low vision had corrected acuities of 20/70 or less in the better eye. Average age of low vision subjects was 40.5 ± 16.7 yr (range 23–74 yr). Mean ages of subjects and controls did not differ significantly (P > 0.1). All low vision subjects were independently ambulatory and had no evidence of gross motor impairment. The causes of low vision were ascertained by history and physical examination, and included a wide spectrum of diseases of the eye and optic nerve, but not the posterior visual pathways. Nine low vision subjects exhibited the typical spontaneous nystagmus associated with severe visual impairment. Four low vision subjects had extensive prior experience with use of telescopic spectacle low vision aids, and nine had little or no experience.

Head velocity was measured by a set of three matched, lightweight angular rate transducers (Watson Industries, Inc., Eau Claire, WI) mounted orthogonally on a comfortable headband and positioned at the top of the head. Transducer outputs were passed through matched low-pass filters (3 db 17 Hz, 4 pole) and digitized at 50 Hz. Head velocity data were collected in five 10 s epochs. The first epoch was always discarded to allow the subject to settle into position. The remaining epochs were then subjected to fast Fourier transformation from 0–25 Hz (resolution 0.1 Hz), and root mean square (RMS) velocity was calculated in each axis. For each axis, epochs were excluded in which RMS values were statistical outliers for excessive velocity. This method, previously described, is designed to exclude the effects of voluntary postural shifts, which can greatly increase variability of the data (5). Aggregate spectra for each axis and subject were computed by averaging epoch spectra at each frequency. For each average spectrum, an automated algorithm identified the peak amplitude component velocity and the frequency at which the component occurred. From these aggregate spectra were computed RMS values, amplitude integrals, and power integrals.

Head velocity was measured under two postural conditions: (1) standing with feet together; and (2) walking in place in synchrony with a metronome beating at 2/s. The metronome rate corresponds to one complete cycle of gait per second, with one footfall at each beat. Subjects were instructed to lift each foot just off the floor during walking in place and to attempt to keep their heads motionless. Subjects wore their shoes.

For each postural condition, head velocity was measured under three viewing conditions in the order listed: (1) eyes closed; (2) eyes open with normal vision; and (3) eyes open wearing 4x binocular telescopic spectacles. The visual surrounding was a perpendicular view of the filled bookshelves, cabinets, and benchtop of a laboratory wall 3 m distant with no corners of the wall visible. As in a natural environment, the visual scene was rich in both horizontal and vertical contours of similar types. The telescopes had a visual field 10.3° in diameter, typical for telescopic spectacles employed as low vision aids. While telescopic spectacles are sometimes employed without masking the unmagnified periphery to improve orientation capability, this situation makes it difficult to be certain if subjects are viewing through or around the telescope elements. For this reason and since failure to mask the periphery is known to reduce visual-vestibular interaction with telescopic spectacles (25), the peripheral visual field was masked.

Results

Standing

Although involuntary head motion is usually not perceived during normal viewing, with telescopic spectacles such motion was readily perceptible. Typical Fourier spectra of head velocity in three axes are illustrated in Figure 1. For both normal and low vision subjects, distributions of spectral component amplitudes typically had a jagged and skewed appearance (Figure 1). The largest components tended to occur at frequencies below 5 Hz, with amplitudes declining as a function
Figure 1. Representative Fourier spectra in roll, pitch, and yaw for four low vision subjects during standing with eyes closed.
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of frequency. Noteworthy exceptions to this pattern were spectra with one or more prominent peaks at frequencies over 5 Hz, such as shown in the first column, third row of Figure 1. Spectral components beyond 15 Hz were negligibly small. The frequency corresponding to the largest component was not systematically influenced by viewing conditions or presence of low vision.

Analysis presented below emphasizes RMS velocity which is a robust measure of intensity of head velocity. This approach is typically used in study of postural sway (1). Other head velocity measures derived by integrating the spectrum (see Methods) were highly correlated with the RMS within identical axis and experimental conditions.

Normally sighted subjects. For normal subjects mean RMS head velocities under the three viewing conditions are illustrated in Figure 2. Mean head velocity in pitch was consistently greater than in roll or yaw. It may be seen that unmagnified vision, and to a slightly greater extent, vision with telescopic spectacles, was associated with reduction in RMS head velocity in each axis. Due to inter-individual variability, the decreases in population mean head velocity during vision did not reach significance (2 tailed t test, P > 0.05). However, when the changes in head velocity due to vision were calculated for each subject, variability was reduced. Significant (P < 0.05) reductions, in the range of 8–13%, were found in pitch and yaw for unmagnified vision, and in roll and pitch for viewing with telescopic spectacles (Figure 3). Due to the method of calculating, the data of Figure 3 cannot be inferred from the population means in Figure 2.

The tendency of head velocity to covary in the three axes was examined in the group of

![Figure 2. Mean RMS head velocities for normal subjects standing quietly with eyes closed, during normal vision (1x), and while wearing telescopic spectacles (4x).](image-url)
normal subjects. Correlations among the three axes for RMS velocities during standing were evaluated using data for the eyes-closed condition. Head velocities in the roll and yaw axes were most tightly correlated \((R = 0.84, P = 0.001)\), with the other pairwise combinations exhibiting less correlation \((R > 0.65, P < 0.05)\).

**Low vision subjects.** For low vision subjects, mean RMS head velocities during standing under the three viewing conditions are illustrated in Figure 4. For all axes and under all viewing conditions, head velocities for the low vision subjects tended to be higher than for the normal subjects (Figure 2). Head velocities were significantly higher \((P < 0.05)\) for low vision subjects only for pitch with eyes closed (13% higher), pitch with normal vision (34% higher), and roll with magnified vision (20% higher). For the low vision population illustrated in Figure 4, it may be seen that neither normal nor magnified vision had much effect on RMS head velocity in any axis. Since the interindividual variability might have obscured the significance of individual changes, the reductions in RMS head velocity due to each visual condition were calculated for each subject. These differences are illustrated in Figure 5. Despite this more sensitive analysis, in none of the three axes was the reduction in RMS head velocity produced by vision statistically significant \((P > 0.05)\).

As was done for the normally sighted subjects, correlation analysis was employed to determine if RMS head velocity covaries in each of the three axes for individual low vision subjects. Significant correlations were found for all pairwise axis combinations during standing with eyes closed \((R > 0.65, P < 0.02)\).

**Walking**

Considerable oscillopsia, the illusory motion of the visual world, was associated with
walking during wearing of telescopic spectacles. For both normal and low vision groups, head velocity spectra during walking were similar. Representative spectra during walking for one normal subject are shown in Figure 6. These spectra contained components over an order of magnitude greater than those obtained during standing, and were dominated by several discrete peaks at integral multiples of the 1 Hz walking frequency. The largest peaks were at odd harmonics (primarily first, third, and fifth) for roll and yaw, but were at even harmonics (primarily second and fourth) for pitch. Significant components were at or below 10 Hz in all axes, with the largest peaks at or below 5 Hz. Frequency of the highest amplitude component peak was not significantly influenced by viewing condition, or the presence of low vision.

Normally sighted subjects. Mean RMS head velocities during walking in place are summarized in Figure 7 for the normal subject population. Compared with the eyes-closed condition, RMS head velocities were slightly but not significantly ($P > 0.05$) reduced in all axes during unmagnified vision. During vision with telescopic spectacles, there were further decreases in all axes, but the difference was significant only for the yaw axis.

Since interindividual variability can obscure trends in the pooled RMS head velocity data, individual differences in head velocity were calculated for each subject by subtracting the values measured with eyes closed from those measured during viewing under each condition. These differences are illustrated in Figure 8. It may be seen that RMS head velocity during unmagnified vision was significantly reduced ($P < 0.005$) in the yaw axis, as compared with the eyes closed condition. Head velocity during magnified vision was significantly ($P < 0.05$) reduced relative to the eyes closed condition in the roll and yaw axes.
These significant decreases were in the range of 17–22%. No significant reduction in RMS head velocity due to normal or magnified vision was observed for the pitch axis.

*Low vision subjects.* For low vision subjects, mean head velocities during walking in place are summarized in Figure 9. There was no significant difference for any axis in the group mean values of RMS head velocity as compared with normal subjects (Figure 7). The differences between RMS head velocities with vision and with the eyes closed were computed on a subject-by-subject basis, and are illustrated in Figure 10. Although no significant change in head velocity was observed for any axis during unmagnified vision (Figure 9), significant ($P < 0.05$) decreases of 14% and 18%, respectively, were observed in roll and yaw during the wearing of 4x telescopic spectacles (Figure 10). As for normal subjects, no significant reductions in RMS head velocity due to normal or magnified vision were observed for the pitch axis.

**Discussion**

In this study, we have confirmed that the human head is an imperfectly stable platform for the eyes. Although ordinarily imperceptible, the head executes constant rotational motion in the roll, pitch, and yaw axes during quiet standing. Both the frequency and intensity characteristics of head velocity during quiet standing varied considerably from subject to subject in both normally sighted and low vision groups, but head velocity was consistently greatest in the pitch axis.

In normally sighted subjects, the effect of
vision on spontaneous head movement during standing was quite consistent: RMS head velocity was reduced, although the degree of reduction was not always statistically significant. Rather than increasing head instability, vision with telescopic spectacles reduced head motion to about the same degree as did unmagnified vision. In contrast, low vision subjects were found to have poorer head stability during standing than the normally sighted, and did not make significant use of magnified or unmagnified visual information to improve stability in any axis. Head velocities during walking in place were much higher than during standing, but were similar for normal and low vision subjects. In normal and low vision subjects, both magnified and unmagnified vision tended to reduce unintended head motion in the roll and yaw, but not the pitch, axes.

It has been proposed that the visual system contributes to postural stability by providing a means of detecting body motion (1). Although spectacle correction of aphakia and
Figure 7. Mean RMS head velocities for normally sighted subjects during walking in place with eyes closed, during normal vision (1×), and while wearing telescopic spectacles (4×).

Figure 8. Reduction in RMS head velocity produced by vision with telescopic spectacles (4×) or unmagnified vision (1×) for normally sighted subjects walking in place. For each subject, values were computed as velocity differences between the eyes closed and viewing conditions.
Figure 9. Mean RMS head velocities for low vision subjects during walking in place with eyes closed, during normal vision (1x), and while wearing telescopic spectacles (4x).

Figure 10. Reduction in RMS head velocity produced by vision with telescopic spectacles (4x) or unmagnified vision (1x) for low vision subjects during walking in place. For each subject, values were computed as velocity differences between the eyes closed and viewing conditions.
anisometropia reportedly induce increases in body sway (1), the data reported here indicate that telescopic spectacles, if they have any effect at all, reduce rather than increase the angular rotational instability of the head in all axes. It appears plausible that this reduction is mediated by magnification of the retinal image slip induced by head movement in the pitch and yaw axes. However, this explanation cannot be directly applicable to the roll axis, in which telescopic spectacles provide no magnification. The explanation for this enigma may lie in the correlation demonstrated among the three rotational axes of head movement. It is obvious that the skeletal musculature is not organized to produce movements in these arbitrary rotational coordinates, and that most skeletal muscles will produce head movements with components in all three rotational axes. Thus a central strategy attempting to minimize the visual feedback of head motion in pitch and yaw might be expected to incidentally reduce head motion in roll as well. Alternatively, the change in mental set during viewing with telescopic spectacles may serve to reduce head instability. An analogous nonspecific effect of viewing condition on body sway has been recently demonstrated (26).

The present evidence of greater head instability in low vision than in normal subjects is supported by studies of the effect of vision on postural sway, the motion of the body's center of gravity (1,12). The investigation of Paulus et al. (1) in normal subjects demonstrated that decreasing visual acuity to 0.3 (20/60) or below increases fore-aft sway more than it does for lateral sway. Although neck and trunk musculature above the center of gravity almost certainly limit the effect of body sway on head rotation, fore-aft sway would tend to produce head rotation in the pitch axis, while lateral sway would tend to produce head rotation in the roll or yaw axis. Despite this supporting evidence, the present study does not implicate reduced acuity alone as the cause of the increased head instability in the low vision subjects. The chronic effects of visual impairment, such as nystagmus, may also contribute to increased head instability in low vision. It has been previously reported that the head stability of low vision patients does not improve following the prolonged use of telescopic spectacles (27).

The majority of low vision subjects in this study had longstanding visual impairment and exhibited nystagmus on clinical examination. While the term sensory-defect nystagmus has been criticized because it does not denote a unique, pendular waveform (28), this term does emphasize the clear relationship between the eye movements and the severity of visual loss that usually occurs early in life (29). Little is known of possible ocular motor or vestibular abnormalities that may coexist with sensory-defect nystagmus. In congenital nystagmus, clinically similar in direction and waveform characteristics, the VOR is reportedly normal (30) and strategies are employed to prolong foveation of visual targets despite superimposed nystagmus (31). Further investigation of visual motion detection and foveation strategy will be required to clarify the mechanisms by which sensory-defect nystagmus influences postural stability.

Although the peak head velocity components during walking in place were typically found to be about tenfold greater than during standing, RMS head velocities during walking in place were modestly less than the values of 10-15°/s reported for the pitch axis during natural walking at 1.4-2.0 steps/s (32). Obviously these values would be higher still during more vigorous ambulation. The first and third harmonics of the walking frequency (1 Hz) tended to dominate the spectra of head movement for the roll and yaw axes, but the second and fourth harmonics dominated the spectra for pitch. This difference is due to the mechanics of gait, in which one full cycle of yaw and roll occur for every two footsteps, while pitch perturbations of the head occur with every footstep (7). If walking in place is typical of natural ambulation, this means that head movements in the pitch axis will tend to occur at higher frequencies than will those in roll and yaw. For both normally sighted and low vision subjects, head velocity spectra during walking included prominent components up to at least 5 Hz, frequencies substantially
above the range of the smooth pursuit visual tracking system (33,34). It is thus likely that purely visual tracking of retinal image motion during walking would not be effective in mediating compensatory eye movements.

Due to the considerable oscillopsia that would be experienced while walking, low vision patients who use telescopic spectacles as visual aids generally stand without voluntary motion when viewing through the telescopes (3). Thus, head motion during standing would closely mimic that encountered in realistic use of telescopic spectacle low vision aids. Even during quiet standing, these unintended head motions have been shown to significantly impair the acuity with 4× telescopic spectacles that would otherwise be achieved by low vision subjects with the head stabilized (35). Imposed head movements of higher velocities produce greater reductions in low vision subjects (5). Imposed head movements having frequency and velocity characteristics similar to those encountered in walking have been shown to produce a many-fold reduction (relative to that measured with head stabilized) in the visual acuity of normally sighted subjects wearing telescopic spectacles (19). The reductions in normally sighted subjects were slightly greater than for the low vision subjects under comparable conditions, so low vision subjects may be marginally more tolerant of the deleterious effects of head instability on visual acuity.

A retrospective clinical study suggests that the sensitivity of DVA to imposed head movement can have significant impact on functional usefulness of telescopic spectacles (5). That study suggested that involuntary pitch axis head instability, rather than yaw, may be most crucial in limiting functional use of telescopic spectacles by low vision patients. It was proposed that the reduction in acuity with telescopic spectacles produced by involuntary head motion may compromise so much of the visual benefit of magnification that the telescopes lose their practical value. The present study provides a potential explanation for the critical nature of pitch stability, since it was found that low vision patients are unable to use vision to reduce unintended head velocity in the pitch axis during either standing (Figure 5) or walking (Figure 10). It is precisely in the pitch axis that the greatest intensity of involuntary head motion is present during quiet standing (Figures 2 and 4).

The unique properties of vertical eye movements may account for the lack of influence of vision on head stability in the pitch axis in low vision subjects. While data on human vertical smooth eye movements have not been obtained in low vision subjects, normal vertical pursuit has been found to be even more limited in frequency and velocity than horizontal pursuit (36). Additionally, visual modulation of the vertical VOR is less effective than for the horizontal system (36). Excellent central vision may be necessary for a strong visual influence on vertical eye movements. Taken together, these observations imply that retinal image slip, and by implication, the degradation of visual acuity due to involuntary head motion, are likely to be most severe in the pitch axis.

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