The Effect of Age on the Vestibular Evoked Myogenic Potential and Sternocecidomastoid Muscle Tonic Electromyogram Level

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Objective: Cervical vestibular evoked myogenic potentials (cVEMPs) are short-latency electromyogram (EMG) evoked by high-level acoustic stimuli recorded from the activated sternocleidomastoid muscle and used to evaluate otolith organ function. The purpose of this study was to investigate the effects of aging on the cVEMP and on the sternocleidomastoid muscle EMG level.

Design: A cross-sectional observational study was used to investigate differences in cVEMP and sternocleidomastoid muscle EMG level in a group of 24 younger and 24 older individuals. cVEMPs were recorded during activation of the sternocleidomastoid muscle at target EMG levels ranging from 0 to 90 µV and during maximum voluntary contraction of the sternocleidomastoid muscle.

Results: The sternocleidomastoid muscle EMG amplitude increased as a function of target EMG level for both age groups; however, the mean EMG amplitude was greater for the younger group than the older group, and the variability of EMG amplitude was greater for the older group. The EMG amplitude at maximum voluntary contraction ranged from 88 to 279 µV for the younger subjects and from 32 to 230 µV for the older subjects, and the mean EMG amplitude at maximum voluntary contraction was significantly greater for the younger group than the older group. The cVEMP amplitude increased as a function of EMG target level for each age group. Although cVEMP amplitude increased as a function of target EMG level for both groups, the older group exhibited smaller cVEMP amplitudes, overall, compared with the younger group. To separate the influence of EMG level from aging on cVEMP amplitude, only the responses obtained at the 30 µV target EMG level were considered for the statistical analysis because there was no significant difference in EMG level between groups at the 30 µV target level. The mean cVEMP amplitudes at the 30 µV target level were 101 and 51 µV for the younger and older groups, respectively, and a statistical analysis indicated that cVEMP amplitude for the younger group was significantly greater than the older group.

Conclusions: The findings suggest that the decrement in cVEMP amplitude is related to both age-related changes in the vestibular system and age-related changes in the sternocleidomastoid muscle. (Ear & Hearing 2011;32:617–622)

INTRODUCTION

Dizziness and imbalance are common reasons that older patients seek medical care from their doctors (Sloane & Baloh 1989). Because dizziness and imbalance are important risk factors for falls in older persons, characterizing the impact of age on the vestibular system is important. The peripheral vestibular system is composed of two types of sensory organs (the semicircular canals and the otoliths) and the two vestibular branches (the inferior and the superior) of the VIIIth nerve. Three semicircular canals respond to angular acceleration, and two otolith organs (the saccule and the utricle) respond to linear acceleration and changes in gravity. The effect of aging on the vestibular system has been demonstrated anatomically. Age-related changes in the vestibular system include loss of sensory hair cells (Johnson et al. 1971; Rauch et al. 2001), otocyst (Igarashi et al. 1993), vestibular nerve fibers, Scarpa's ganglion cells (Richter 1980; Park et al. 2001), and vestibular nucleus neurons (Lopez et al. 1997; Tang et al. 2001). Anatomical changes related to aging in the vestibular system are known, whereas the evidence for age-related changes in vestibular function is less conclusive. Most studies on age-related changes in vestibular function have focused on the semicircular canal function via measurement of the vestibulo-ocular reflex (Peterka et al. 1990; Hajioff et al. 2000; Baloh et al. 2001), but recently, the effect of aging on otolith organ function has been investigated (Furman & Redfern 2001; Welgampola & Colebatch 2001; Kobayashi et al. 2002).

Although postural stability is dependent on input from multiple sensory systems (i.e., visual, somatosensory, and vestibular), the otolith organs provide the primary vestibular contribution for postural control. Changes in postural stability are well documented in the elderly (Belal & Glorig 1986; Horak et al. 1989), and recently, Serrador et al. (2009) demonstrated that age-related loss of otolith-ocular function is associated with increased postural sway. Determining age-related changes in otolith organ function, therefore, is necessary for understanding the effects that aging has on balance and postural stability.

The cervical vestibular evoked myogenic potential (cVEMP) has been used to evaluate otolith organ function and has been established as a clinical test of saccular and/or inferior vestibular nerve function (Colebatch 2001). cVEMPs are short-latency electromyogram (EMG) evoked by high-level acoustic stimuli recorded from surface electrodes over the sternocleidomastoid (SCM) muscle during prolonged contraction. Several studies have shown a decrement in cVEMP amplitude in individuals older than 60 yrs (Welgampola & Colebatch 2001; Ochi & Ohashi 2003; Su et al. 2004; Zapala & Brey 2004; Basta et al. 2005; Basta et al. 2007; Brantberg et al. 2007). However, it is unclear whether the amplitude decrements are influenced by age-related changes in the vestibular system or age-related changes in the SCM muscle. cVEMP amplitude is proportional to the magnitude of the muscle contraction recorded from surface electrodes on the SCM muscle (tonic EMG level) (Akin et al. 2004), and age-related loss of muscle fibers, axons, and motor neurons has been documented (Campbell et al. 1974; Benassi et al. 1990). The purpose of this study
was to investigate the effects of aging on the cVEMP and on the SCM muscle tonic EMG level.

**SUBJECTS AND METHODS**

**Subjects**

Twenty-four young individuals (22 to 31 yrs, mean age = 24.3, SD = 2.5) and 24 older individuals (61 to 86 yrs, mean age = 70.5, SD = 5.8) were studied. The younger subjects had normal hearing sensitivity (≤20 dB HL, ANSI 2004) at octave intervals from 250 to 8000 Hz. For the older subjects, the mean pure-tone average of 250 to 8000 Hz ranged from 8 to 63 dB HL (mean = 26 dB HL). All subjects had negative histories of middle ear pathology, vestibular, cervical and neurological disease. Normal vestibular function was confirmed with rotational chair testing (Micromedical Technologies, Inc.). Infrared video goggles were used to record eye movement during angular sinusoidal rotation about the rostral-caudal body axis at frequencies ranging from 0.01 to 0.64 Hz. The subject was seated in a chair enclosed in a light-proof booth with the head positioned upright, and instructed to perform mental alerting tasks to prevent central suppression of the vestibulo-ocular reflex response. Normal vestibular function was defined as slow component velocity phase, gain, and asymmetry data within normal values at 0.01 through 0.64 Hz.

**Procedures**

To control directly the influence of tonic EMG level on the cVEMP, EMG and cVEMPs were recorded simultaneously from one side of each subject (Akin & Murnane 2001). Subjects were seated upright and asked to rotate their heads to activate unilaterally the SCM muscle. A two-channel EMG recording was obtained with a stand-alone differential surface electrode (DelSys, Inc., DE-2.1) placed at the midpoint of the SCM muscle, and a reference electrode was attached to the wrist. The EMG signals were amplified (10,000), band-pass filtered from 20 to 450 Hz, and digitized at 1024 Hz via a portable EMG unit (DelSys, Inc., Bagnoli-2). The subjects were provided visual feedback of their EMG amplitude via the computer monitor and software (Delsys, Inc., EMGworks Signal Acquisition and Analysis Software). Subjects were instructed to maintain SCM muscle EMG amplitude at randomized tonic EMG levels of 0, 10, 30, 50, 70, and 90 μV for the duration of each trial. In addition to the six target tonic EMG levels, EMG amplitudes were measured during maximum voluntary contraction (MVC). The mean EMG amplitude was calculated for each target level and at MVC.

cVEMPs were recorded using a 500-Hz Blackman-gated tone burst (rarefaction onset, two-cycle rise-fall time with no plateau) and presented at 120 dBpeak SPL (90 dB nHL). A two-channel recording of the evoked response was obtained with noninverting electrodes placed at the midpoint of the SCM muscle, inverting electrode sites at the sternocleidovascular junctions, and the ground electrode on the forehead. Tone bursts were presented to the ear ipsilateral to the activated SCM muscle via ER3A (Etymotic Research) insert earphones at a repetition rate of 5/sec. The cVEMP response was amplified (5000) and band-pass filtered from 20 to 1500 Hz with a 12 dB/octave slope (Nicolet, Spirit 2000). The 100-msec epochs included a 20-msec prestimulus baseline. Responses to 128 stimuli were averaged, and three responses were obtained from each subject at the randomized rectified tonic EMG target levels (0, 10, 30, 50, 70, and 90 μV) and at MVC.

**RESULTS**

**Effects of Age on Tonic EMG Level**

For both age groups, the EMG amplitude increased as a function of target EMG level. Figure 1 shows a bivariate plot of the individual EMG amplitude as a function of the target EMG level for younger (filled circles) and older (open circles) individuals. The solid diagonal line represents the condition in which the actual tonic EMG level equals the target level. The dashed line represents the linear regression analysis of target EMG level for the younger individuals (y = 0.43 + 0.98x; r² = 0.95). The dotted line represents the linear regression analysis of target EMG level for the older individuals (y = 9.55 + 0.71x; r² = 0.82).

Fig. 1. Bivariate plot of the individual EMG amplitude as a function of the target EMG level for younger (filled circles) and older (open circles) individuals. The solid diagonal line represents the condition in which the actual tonic EMG level equals the target level. The dashed line represents the linear regression analysis of target EMG level for the younger individuals (y = 0.43 + 0.98x; r² = 0.95). The dotted line represents the linear regression analysis of target EMG level for the older individuals (y = 9.55 + 0.71x; r² = 0.82).

In the younger group, the SDs for EMG amplitude (SD = 1.5 to 4.3) were similar for target EMG levels ranging from 0 to 70 μV, indicating little variability in EMG amplitude across subjects at target levels ≤70 μV (Table 1). At the 90 μV EMG target level, however, the variability of EMG amplitude increased for the younger subjects (SD = 12.4). In contrast, the variability of EMG amplitude increased over the entire range of target EMG level for the older group. The SDs for the older group ranged from 1.8 to 2.9 for target EMG levels ≤30 μV, indicating little variability in EMG amplitude. At target levels >30 μV, however, the variability
of EMG amplitude increased as a function of target EMG level (SD = 6.1, 10.5, and 16.7 at 50, 70, and 90 μV EMG target levels, respectively).

A 2 × 6 (age group × target EMG level) mixed-model analysis of variance (ANOVA) with repeated measures was computed for EMG amplitude. Results indicated a main effect for age group ($F[1, 23] = 27.13$, $p < 0.0001$) and target EMG level ($F[5, 42] = 822.64$, $p < 0.0001$). The interaction between target EMG level and age group was significant ($F[5, 42] = 6.48$, $p < 0.0001$). Post hoc analyses indicated that the tonic EMG levels for the older group were significantly lower than the younger group for the 10, 50, 70, and 90 μV target levels.

In contrast, there was no significant difference between groups at the 30 μV target level.

The individual and mean EMG amplitude levels obtained during MVC of the SCM muscle are plotted for both age groups in Figure 2. The EMG amplitude obtained at MVC ranged from 88 to 279 μV for the younger subjects and from 32 to 230 μV for the older subjects. The mean EMG amplitude at MVC was greater for the younger group (mean = 174 μV, SD = 54.45) than for the older group (mean = 97 μV, SD = 52.25). A univariate ANOVA was computed for MVC tonic EMG level, and the main effect for age group was significant ($F[1, 47] = 25.25$, $p < 0.0001$).

### Effects of Age on cVEMP Amplitude

Representative cVEMP waveforms obtained at target EMG levels are shown for a younger and an older subject in Figure 3. VEMPs were obtained from both subjects at 30 to 90 μV EMG target levels. No responses were obtained from either subject at the 10 or 0 μV EMG target level. For both subjects, the cVEMP amplitude increased with target EMG level, whereas the latency was unchanged. Larger cVEMP amplitudes were obtained from the younger subject than the older subject.

For the younger group, cVEMPs were present in all individuals at EMG target levels from 30 to 90 μV, whereas

### Table 1. Means and SDs for actual EMG amplitude, VEMP amplitude, and P1 and N1 latency for each age group at each target EMG level

<table>
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n, number of subjects with VEMPs present; Y, younger group; O, older group.
cVEMPs were absent at the 10 μV EMG target level for two individuals and at the 0 μV target level for 24 (all) individuals. For the older group, cVEMPs were present for most individuals at the 30, 50, and 70 μV EMG target levels; however, cVEMPs were absent at the 90, 10, and 0 μV EMG target levels for 8, 17, and 24 (all) subjects, respectively.

The individual P1-N1 cVEMP amplitudes are plotted as a function of target EMG level for both groups in Figure 4. For each age group, the cVEMP amplitude increased as a function of EMG target level. The dashed and dotted lines fit to the data are the linear functions of target EMG level for the younger and older age groups, respectively. The equations that describe each function and the $r^2$ values are indicated in the figure legend. The correlation between target EMG level and P1-N1 amplitude was significant for both younger subjects (N = 119, $p < 0.0001$, $r^2 = 0.52$) and older subjects (N = 119, $p < 0.0001$, $r^2 = 0.16$).

Fig. 4. Individual P1–N1 cVEMP amplitude as a function of EMG target level for younger (filled circles) and older (open circles) individuals. The dashed line represents the linear regression analysis for the younger subject group ($y = -17.59 + 3.83x; r^2 = 0.52$). The dotted line represents the linear regression analysis for the older subject group ($y = 14.93 + 1.03x; r^2 = 0.16$). Because many of the data points overlap, the number of individuals with cVEMPs present at each target level is provided by the numeric values in the parentheses for the younger and older age groups, respectively.

Although cVEMP amplitude increased as a function of target EMG level for both groups, the older group exhibited smaller cVEMP amplitudes, overall, compared with the younger group. To separate the influence of tonic EMG level from the influence of aging on cVEMP amplitude, only the responses obtained at the 30 μV target EMG level were considered for the statistical analysis. This level was selected because there was no significant difference in tonic EMG level between groups at the 30 μV target level. The mean P1-N1 amplitudes at the 30 μV target level were 101 μV (SD = 48) and 51 μV (SD = 38) for the younger and older groups, respectively (Table 1). A univariate ANOVA was computed for cVEMP amplitude, and the main effect for age group was significant ($F[1, 47] = 16.02, p < 0.0001$), indicating that cVEMP amplitude for the younger group was significantly greater than the older group.

Effects of Age on VEMP Latency

The means and SDs for VEMP latency are shown in Table 1 for both age groups at each EMG target level. For the younger group, P1 latency ranged from 13.8 to 19.2 msecs across EMG target levels, and N1 latency ranged from 20 to 28 msecs. For the older group, P1 latency ranged from 11.2 to 19.2 msecs across EMG target levels, and N1 latency ranged from 20.6 to 28.4 msecs. The individual P1 and N1 latencies are plotted as a function of target EMG level in Figure 5 for younger (filled circles) and older (open circles) subjects. The dashed lines fit to the data in each panel are linear functions of target EMG level. The equations that describe each function and the $r^2$ values are indicated in the figure legend. For P1 latency, the correlation coefficients were not significant for either group ($p > 0.05$). For N1 latency, the correlation was significant for the younger subjects (N = 116, $p < 0.001$, $r^2 = 0.10$) but not for the older subjects ($p > 0.05$).

Two separate 2 × 4 (age group × target EMG level) mixed-model ANOVAs with repeated measures were computed for P1 and N1 latency data. For P1 latency, the main effect of target EMG level was not significant ($F[3, 34] = 1.42, p = 0.25$), and there was no significant main effect of group ($F[1, 36] = 0.24, p = 0.63$). For N1 latency, the main effect of target EMG level was significant ($F[3, 34] = 9.04, p < 0.0001$). There was no significant main effect of group ($F[1, 36] = 0.89, p = 0.35$).

DISCUSSION

The effects of age on cVEMP amplitude are well established, and numerous studies have determined a decrement in amplitude in individuals older than 60 yrs (Welgampola & Colebatch 2001; Ochi & Ohashi 2003; Su et al. 2004; Zapala &
in this study, cVEMP amplitude was decreased in a group of older individuals compared with a group of younger individuals. Although cVEMP amplitude is proportional to the tonic SCM muscle EMG level, the age-related decrement in cVEMP amplitude has been attributed to age-related changes in the vestibular end organ and central pathways rather than age-related changes in the tonic SCM muscle EMG level (Ochi & Ohashi 2003). The purpose of this study was to further examine the effects of aging on both the cVEMP and the SCM muscle tonic EMG level.

It is well known that aging causes a loss of muscle fibers, axons, and motor neurons (Campbell et al. 1974; Benassi et al. 1990), and recently, Uthaikhop and Jull (2009) demonstrated an age-related decrease in the amplitude of surface EMG recorded from the SCM muscle during extension and flexion of the neck. Furthermore, Kuhlman (1993) demonstrated a 25% reduction in the mean cervical range of motion in individuals aged 70 to 90 yrs compared with 20 and 30-yr-olds. During cVEMP testing, the head is often turned laterally to activate the SCM muscle, and there are no previous studies of the effect of aging on the SCM muscle during lateral head rotations.

To determine the influence of aging on the SCM muscle, tonic EMG levels were measured in a younger and older group of individuals at five target EMG levels and during MVC. Both younger and older subjects were able to achieve the target EMG levels of 30 and 50 μV during unilateral activation of the SCM muscle; however, the older subjects had more difficulty achieving target levels ≥50 μV. In addition, older individuals demonstrated lower tonic EMG levels during MVC of the SCM muscle compared with the younger group. These findings suggest an age-related decrease in the magnitude of SCM muscle activation during lateral rotation of the head.

Previous studies have used the mean prestimulus rectified EMG from the evoked potential recording as a measure of SCM muscle activation and reported that EMG does not decrease with age (Welgampola & Colebatch 2001; Basta et al. 2007). This finding is in contrast with this study that demonstrated age-related changes in SCM muscle tonic EMG level. The disparity in the age effect findings for EMG may be related to methodological differences in the measurement of SCM muscle tonic EMG level across studies. First, differential surface electrodes were used in the present study and placed on the midpoint of the SCM muscle to provide a more direct measurement of tonic EMG level by decreasing the contribution of noise recorded from the SCM muscle (de Luca 2006). In contrast, the prestimulus rectified EMG is typically measured using an active single contact electrode placed on the midpoint of the SCM muscle and a reference single contact electrode placed on the clavicle or sternum (Welgampola & Colebatch 2001), which increases the possibility of cross-talk (recording from adjacent muscles) (de Luca 2006). Second, in the present study, participants were instructed to activate their SCM muscle at target EMG levels and at MVC. In contrast, previous studies either did not monitor for EMG or used a wide EMG target range, typically 50 to 200 uV, rather than a specific target level (Basta et al. 2007).

Although age-related change in SCM muscle activation was observed at EMG target levels of ≥50 μV and at MVC, there was no significant difference between age groups at the 30 μV target level. The decrement in cVEMP amplitude at 30 μV, therefore, is attributable to age-related changes in the vestibular system rather than an age-related change in the SCM muscle. This finding is similar to previous studies that controlled for the influence of individual side differences in the SCM muscle activation on cVEMP amplitude by using corrected amplitudes where the cVEMP amplitude is divided by the mean prestimulus rectified EMG (Welgampola and Colebatch 2001). The use of a corrected amplitude eliminates the effects of EMG; therefore, any age-related decrements in cVEMP amplitude are more likely attributed to an age-related change in vestibular (saccular) function. In the present study, the EMG recording method (direct recording of EMG using target EMG levels) allowed for differentiation of the effects of age on tonic EMG level from the effects of age on VEMP amplitude.

A methodological consideration of this study is the possibility of a gender effect on SCM muscle tonic EMG level. A review of the data determined that the younger group was composed of 17 females and 7 males, and the older group was composed of 15 females and 9 males. The two age groups, therefore, were approximately gender-matched. An independent samples t test using seven randomly chosen young females and the seven young males revealed that there were no significant gender differences for the younger age group for tonic EMG level at target levels of 0 to 90 μV (t = −0.106, df = 82, p = 0.915). Similarly, an independent samples t test using nine randomly chosen older females and the nine older males revealed that there were no significant gender differences for the older age group for EMG level using target levels of 0 to 90 μV (t = −0.385, df = 109, p = 0.701). These results are consistent with Basta et al. (2007) who reported no gender effects for EMG level. Interestingly, for EMG level recorded during maximum voluntary contraction of the SCM muscle, there was a gender effect for the younger age group (t = 5.165, df = 12, p < 0.001) but not for the older age group (t = −0.975, df = 16, p = 0.344). As VEMPs were not recorded during maximum voluntary contraction of the SCM muscle, the age-related changes in VEMP amplitude observed in this study were not related to gender effects.

The findings of the present study suggest that the decrement in cVEMP amplitude can be attributed to both age-related changes in the vestibular system and age-related changes in the SCM muscle. The cVEMP amplitude was affected by age-related changes in the SCM muscle when activated at higher tonic EMG levels (≥50 μV), and Figure 4 shows that several older participants had cVEMPs present at 30 μV but not at higher EMG target levels. In contrast, SCM muscle tonic EMG level had no effect on the presence of the cVEMP in younger subjects. These findings suggest that use of a lower EMG target level may increase the likelihood of recording a cVEMP in some older patients.

The main finding that cVEMP amplitude decreases with age is consistent with anatomical and functional evidence of age-related changes in the vestibular system. In addition to changes in sensory cells, both animal and human studies have demonstrated an effect of age on otoconia. Otoconia are calcium carbonate crystals that increase the density and weight of the otolithic membrane and cause the otolith organs to be sensitive to changes in gravity. Although otoconia typically undergo a cyclical degeneration and regeneration process, Suzuki et al. (1997) demonstrated that regeneration of otoconia...
is reduced in older mice. In humans, the volume of otoconia in the maculae of older individuals is reduced significantly compared with younger individuals (Ross et al. 1976; Igarashi et al. 1993). This finding is consistent with the increase in the prevalence of benign paroxysmal positioning vertigo in older patients, most likely resulting from canalithiasis or otoconia floating in the semicircular canals.

Determining the age-related changes in otoconial organ function is important because the otoconial organs provide the primary vestibular input for postural control, and numerous studies have demonstrated that disequilibrium, spontaneous postural sway, and fall risk increase with age (Belal & Glorig 1986; Horak et al. 1989; Sattin et al. 2000). Recently, Serrador et al. (2009) demonstrated an age-related reduction in otolocular counterrolling that correlated strongly with an increase in mediolateral postural sway. These results suggested that age-related changes in otolocular function may contribute to an increase in fall risk in the elderly.

The presumed cVEMP pathway includes the saccule, inferior vestibular nerve, brain stem vestibular nuclei, the descending medial vestibulospinal tract, the accessory nucleus, the accessory nerve, and the motoneurons of the SCM muscle. Because there is substantial evidence that aging occurs throughout the vestibular system, the age-related decrement in cVEMP amplitude may reflect age-related changes throughout the sacculo-collic pathway.

In summary, to determine the effect of aging on the cVEMP, we measured directly the tonic EMG level of the SCM muscle during the cVEMP recording. The findings of the present study suggest that the decrement in cVEMP amplitude is related to both age-related changes in the vestibular system and age-related changes in the SCM muscle.

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