J. Phys. Ther. Sci.
25: 281–285, 2013

Postural Stability and Visual Verticality Perception of Neck Disturbance of the Middle-aged during Quiet Standing

Wanvisa Panichaporn[1)], Vimonwan Hiengkaew[1)], Sumethee Thanungkul[2)], Roongtiwa Vachalathiti[1)], Alongkot Emasithi[3)]

[1)] *Faculty of Physical Therapy, Mahidol University: 999 Phutthamonthon 4 Rd, Salaya, Phutthamonthon, Nakhon Pathom 73170, Thailand. TEL: +66 2-441-5450, FAX: +66 2-441-5454, E-mail: vimonwan.hie@mahidol.ac.th*
[2)] *Center of Biomedical Instrument Research and Development, Institute of Molecular Biosciences, Mahidol University*
[3)] *Department of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University*

Abstract. [Purpose] This study investigated postural stability and visual vertical perception of healthy middle-aged subjects before and after induction of dorsal neck muscle fatigue. [Subjects] Fourteen subjects (3 males, 11 females) were recruited from the community. [Methods] To induce neck extensor muscle fatigue, participants pushed their heads against a myometer. The average center of pressure (COP) displacement in the medial-lateral (ML) and anterior-posterior (AP) directions and average sway velocity were measured on a force platform, and the error in visual vertical perception was measured using the rod and frame test. [Results] The average COP displacement in the AP direction and average sway velocity were significantly different between before and after induction of neck muscle fatigue. No difference in the average COP displacement in the ML direction or errors in visual verticality perception was observed before and after neck muscle fatigue. [Conclusion] In the presence of visual input, dorsal neck muscle fatigue induced postural instability, but not visual vertical misperception. After isometric or repetitive neck extensor muscle contraction for a long period, taking a rest for a while before changing posture from sitting to standing is recommended for workers, to avoid an increase in postural sway in standing, which may lead to an accidental fall.
Key words: Neck, Postural balance, Visual verticality

(This article was submitted Sep. 20, 2012, and was accepted Oct. 31, 2012)

INTRODUCTION

Neck information plays an important role in postural maintenance. It provides information on the position of the head and body[1–5)] as well as motions and localizations of visual objects[2–6)]. The neck functions in body balance maintenance through activity of the high density of deep neck muscle spindles[7)]. Vibration of dorsal neck muscles stimulates neck proprioceptive inputs[8–10)], and changes proprioceptive signals code of body spatial orientation and postural stabilization[11)]. An increase in forward leaning was induced by neck muscle vibration during static standing, which has been explained as a response to the perception of the lengthening of the dorsal neck muscles[12)].

Muscle fatigue is the loss of force during sustained contraction. For submaximal contractions, muscle fatigue shows an increase in the amplitude of electromyograms (EMG) and a decrease in the median frequency of EMG[13)]. Neck muscle fatigue is reported to influence postural control and may disturb subjective postural reference. Neck extensor muscle fatigue increases body sway, in addition to changing body direction[14–17)]. A study reported that after 5 minutes of intense contraction of approximately 35% of maximal voluntary contraction of the dorsal neck muscles the body sway increased during quiet standing[15)]. A load of 25% maximal isometric contraction of the neck extensor muscles for 10 and 15 minutes duration produced significant changes in center of pressure (COP) sway[14)], which is believed to be caused by metabolic accumulation in the neck muscles[13, 18)] and decreased neck joint position sense[19, 20)].

Disturbance of cervical proprioception altered not only postural balance but also vertical perception. Vertical perception is the interaction of the visual, proprioceptive, and vestibular systems for orienting the body with external objects in space. Body movement and stability of postural control are related to vertical perception[21, 22)]. Mistakes by individuals with neck pain in judging the visual vertical in the rod and frame test have been reported[23–25)]. Neck muscle pain is associated with neck muscle fatigue[26, 27)]. To our knowledge, vertical perception has not been examined in individuals with only neck muscle fatigue.

People suffering minor neck problem but are not yet receiving any treatment showed neck muscle fatigue presenting a reduction in endurance time of the neck

Table 1. Means and standard deviations of electromyography data; median frequency (Hz) and amplitude (μv), during the first (1st) and the fifth (5th) minutes of neck muscle fatigue

	Neck muscle fatigue			
	The 1st minute		The 5th minute	
	Left side	Right side	Left side	Right side
Median frequency (Hz)	57.9 ± 14.7	60.4 ± 11.1	50.6 ± 13.4*	54.0 ± 11.7#
Amplitude (μv)	6.70 ± 2.83	7.30 ± 3.23	8.70 ± 3.67*	8.62 ± 3.58#

* $p \le 0.05$ significant difference between the 1st and the 5th minutes on the left side. # $p \le 0.05$ significant difference between the 1st and the 5th minutes on the right side

muscles[28]. Repetitive occupational or static work causes an increased risk of muscle disorders[29]. Only 10% of muscle contraction at maximal voluntary effort produces intramuscular pressures that cause partial restriction of blood flows[30, 31] which may increase metabolic accumulation. Nowadays, the number of computer workers is high, and most of them are middle-aged[32], between 35 and 60 years of age. The neck region is a common musculoskeletal symptom among computer users[32, 33]. In addition, the middle-aged show declines in postural stability and the sensory systems used to controlling posture[34–36]. To avoid the influence of age on postural control and balance, the present study focused on the middle-aged. The aim of the present study was to compare postural stability and visual vertical perception of healthy middle-aged subjects before and after neck extensor muscle fatigue. We hypothesized that dorsal neck muscle fatigue would induce postural instability and errors in visual vertical perception. We hope that the present study will contribute to the knowledge concerning the work-related health of middle-aged workers.

SUBJECTS AND METHODS

Subjects

Fourteen healthy adults (3 males and 11 females) aged between 36–54 years (mean age ± SD = 44.4 ± 5.96 years) participated in this study. Subjects were recruited from the general community. They were excluded from the study if they had tumors, trauma, fractures, inflammatory disorders, neurological disorders, upper and/or lower extremity impairments, visual impairments, and vestibular deficits. All participants were informed of the purpose and the protocol of the study before they signed consent forms. The study protocol was approved by Institutional Review Board of Mahidol University.

Methods

To induce neck muscle fatigue, subjects flexed their necks about 15° and a myometer was set at the occipital level of their heads. The surface EMG electrodes were attached on both sides of neck paravertebral muscles using midcervical paraspinal placement, covering the capitis and cervicis groups as well as the upper trapezius[37]. The amplitudes (μv) and median frequencies (Hz) of EMG were measured simultaneously by an 8-channel surface electrode electromyograph (Naroxon INC., USA © 2006) with a sampling frequency of 1500 Hz and band-pass filtered between 20–500 Hz. Each participant pushed his/her head against the myometer for 5 minutes. The force set for the myometer was 1/3 maximum voluntary contraction of each subject's neck extensor muscles[15]. The participants were able to stop if they felt fatigue or uncomfortable. The amplitudes and median frequencies of the EMG of the neck muscles at the 1st and the 5th minute are in Table 1. They demonstrate neck extensor muscle fatigue after pushing against the myometer for 5 minutes. None of participants reported pain.

Postural stability and visual verticality perception were measured before and immediately after inducing neck muscle fatigue. The participants were instructed to stand barefoot with their feet apart at a distance of 11% of body height[38] and their arms hanging besides the body on a force platform (AMTI model OR6-7) for 20 s. To measure postural stability, the signals from the force platform were sampled at 50 Hz and processed with a 4th order Butterworth low pass filter with a cut-off frequency of 8 Hz. COP was expressed as the average displacement in the medial-lateral (ML) and the anterior-posterior (AP) directions, and average velocity was calculated as follows.

The average displacement in the ML direction =

$$\frac{\sum_{i=1}^{N} |x_i - \text{COP-ML average}|}{N}$$

The average displacement in the AP direction =

$$\frac{\sum_{i=1}^{N} |y_i - \text{COP-AP average}|}{N}$$

The average sway velocity =

$$\frac{\text{Total length (L) of the COP path}}{\text{The total number of frames (n)* the total change in time } (\Delta t)}$$

Furthermore, to evaluate the visual vertical perception, rod (13 cm) and frame (18 cm × 15 cm) apparatus was

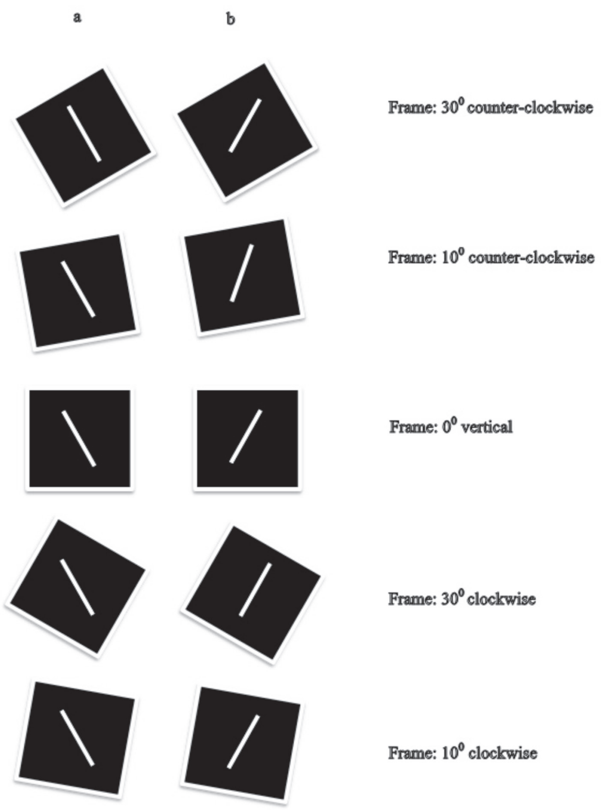

Fig. 1. The rod and frame apparatus. The five frame positions: 30° counter-clockwise, 10° counter-clockwise, 0° vertical position, 10° clockwise, and 30° clockwise with the rod rotated about 28° to the left (a) and the right (b). Participants were required to adjust the rod to the vertical position.

created by Labview program version 6.1 and was shown on a 19-inch monitor (Fig. 1). In a dark room, the monitor was placed at eye level 100 cm in front of a seated subject. On the monitor, the rod and frame were rotated independently using a computer mouse. A researcher rotated the frame randomly to five positions: 30° counter-clockwise, 10° counter-clockwise, 0° vertical, 10° clockwise, and 30° clockwise (Fig. 1). The rod was tilted about 28° to the left or to the right of the frame. Participants were required to adjust the rod back to the vertical position. The absolute angle of the rod deviated from the vertical in each rotated frame was measured. Participants performed 10 trials. The average errors were calculated, and presented as the bias of visual verticality perception.

The paired t-test was used to compare the average COP displacement in the ML and the AP directions, the average sway velocity, as well as errors in visual verticality perception between before and after neck muscle fatigue. Statistical significance was accepted for value of $p \leq 0.05$.

RESULTS

As shown in Table 2, no difference was observed in the average COP displacement in the ML direction between before and after neck muscle fatigue (p=0.593). However, the average COP displacement in the AP direction showed significant difference between before and after induction of neck muscle fatigue (p=0.021). The average sway velocity was significantly different between before and after induction of neck muscle fatigue (p=0.031). No difference was observed in errors of visual verticality perception between before and after induction of neck muscle fatigue (p=0.151).

Table 2. Mean and standard deviations of the displacement of center of pressure (COP) in the medial-lateral (ML) (cm) and the anterior-posterior (AP) (cm) directions, mean values of the sway velocity (cm/s), and mean errors of visual verticality (degrees) before and after neck muscle fatigue

	Neck muscle fatigue	
	Before	After
Displacement of COP in the ML (cm)	0.14 ± 0.08	0.15 ± 0.07
Displacement of COP in the AP (cm)	0.28 ± 0.10	0.36 ± 0.16*
Sway velocity (cm/s)	1.30 ± 0.21	1.45 ± 0.33*
Error in visual verticality (degrees)	0.80 ± 0.45	0.95 ± 0.43

* $p \leq 0.05$ significant difference between before and after neck muscular fatigue

DISCUSSION

Postural stability and visual vertical perception of middle-aged subjects before and after induction of neck extensor muscle fatigue was investigated. In the presence of visual information, dorsal neck muscle fatigue demonstrated a significant effect on postural balance, indicating an increase in average COP displacement in the AP direction and sway velocity. In contrast, average COP displacement in the ML direction was not significantly different between before and after induction of neck muscle fatigue. Visual vertical perception was similar between before and after induction of dorsal neck muscle fatigue.

In the present study, submaximal contraction of dorsal neck muscles showed fatigue through EMG. Generally, prolonged and low-level static contraction of the muscles increases EMG amplitude and decreases the mean spectral frequency of the EMG power spectrum[39)]. In submaximal contractions, an increase in amplitude and a decrease in frequency of the EMG are markers of muscle fatigue[13)]. The increase in EMG amplitude is related to the increase in the number of motor units compensating for the loss of contractility[40)]. A decrease in EMG frequency power spectrum toward lower frequency results from accumulation of the metabolic substance. An increase in venous blood lactate samples appears simultaneously with a statistically significant decrease in median frequency[40)].

The present results show increases in average COP displacement in the AP direction and sway velocity of the middle-aged subjects after induction of neck muscle fatigue. However, no change in average COP displacement in the ML direction was observed. Neck muscle fatigue can be considered as neck disturbances and it is likely to change somatosensory inputs. The alteration in proprioception information immediately interacts with visual and vestibular inputs leading to postural instability[14, 15, 41]. The mechanism of muscle fatigue is unlike that of muscle vibration. Muscular vibration is a mechanical disturbance of the neck muscles. Many investigations have used neck muscle vibration as a stimulus to elicit proprioceptive input[10, 42–44]. Vibration of the neck muscles produces an increase in body sway and an inclination of the body toward the side contralateral to the vibrated muscle[43, 44]. A possible mechanism affecting postural balance during neck muscle fatigue is blood flow impairment and inflammatory substance accumulation, for example, potassium, lactic acid, bradykinin, and arachidonic acid[13]. Muscle fatigue alters the discharges of muscle spindles[45]. Such a change in muscle spindle inflow would adversely affect postural control. We agree with the implication of a previous study[15], that localized neck extensor muscle fatigue affects the mechanisms of postural control by presenting atypical sensory information from muscle spindles thereby eliciting postural instability. In the present study, neck muscle fatigue elicited postural instability in the AP direction and an increase in sway velocity. Therefore, we assume that a change in sensory information elicited by dorsal neck muscle fatigue influences COP displacement in the AP direction and sway velocity.

The lack of change in COP displacement in the ML direction is possibly the result of participants having stood with their feet apart, a position that helps to reduce the role of the ankle and hip strategy in the frontal plane[46]. Moreover, standing with eyes open stabilizes posture[17]. Another factor related to postural stability is strength of the lower limb muscles[47–49]. The lack of change in COP displacement in the ML direction could also be explained by the strength of lower limb muscles, since the participants were able walk and do activities of daily living independently. Unfortunately, the strength of the lower limb muscles was not recorded as it was not an outcome of interest in this study. We suggest it would be additional useful information in future investigation.

We expected to observe errors in visual vertical perception in the middle-aged subject after neck muscle fatigue, but the results did not show it. Disturbances to visual vertical perception occur as a result of errors in sensory input from the vestibular, visual, and proprioceptive systems, or at the level of integration of these signals within the brain[50]. Visual vertical perception is used to damage to the central nervous system and vestibular networks such as in brain injury, stroke, or vestibular dysfunction[51–54]. In patients with neck pain, proprioceptive disturbances lead to difficulties in vertical perception and spatial orientations[23, 25] since it stimulates the small afferent fibers of joint receptors or small segmental muscles around vertebral articulations influencing on the central nervous system and tonic neck reflex[55, 56], subsequently affecting spatial orientation[55]. It has been reported that muscle fatigue can activate pain by ischemia[13]. In the present study, none of our participants reported pain after induction of neck muscle fatigue. Thus, the level of fatigue in the dorsal neck muscles may not have been sufficient enough to disturb the sensory systems affecting vertical perception. We assume that dorsal neck muscle fatigue without neck pain does not induce a change in visual vertical perception because of inadequate disturbance of the neck proprioceptive system. Consequently, there was no disturbance of the central nervous system.

Prolonged work may induce intramuscular pressures related to muscle fatigue. Neck and shoulder muscle activities are high in repetitive and static work postures, especially in the static sitting posture with the whole spine flexed[57]. In the present study, the middle-aged subjects with dorsal neck muscle fatigue showed increased postural sway in the AP direction and sway velocity. For avoiding accidental fall in changing posture from sitting to standing or in standing position after static work postures, we suggest resting for a while, at least 5 minutes[15], to reduce dorsal neck muscle fatigue. This would improve blood flow to the muscles and reduce metabolic accumulation. Moreover, appropriate exercises to increase dorsal neck muscle endurance are recommended for people who perform in work repetitive and static postures, for example computer users. A possible exercise would be isometric exercise of the neck extensor muscles, hold for 10 s, 10–15 repetitions a set[58].

In conclusion, dorsal neck muscle fatigue induces postural instability in the AP direction, increases sway velocity, and appears no to effect ML sway displacement or visual vertical perception. Fatigue without neck pain appears not to disturb visual vertical perception. Middle-aged workers, particularly computer users, should rest for a while after working in the sitting position before changing posture to standing, and we also suggest they should perform neck extensor muscle endurance exercises.

REFERENCES

1) Mergner T, Siebold C, Schweigart G, et al.: Human perception of horizontal trunk and head rotation in space during vestibular and neck stimulation. Exp Brain Res, 1991, 85: 389–404. [Medline] [CrossRef]
2) Mergner T, Rottler G, Kimmig H, et al.: Role of vestibular and neck inputs for the perception of object motion in space. Exp Brain Res, 1992, 89: 655–668. [Medline] [CrossRef]
3) Smetanin BN, Popov K, Shlykov V: Postural responses to vibrostimulation of the neck muscle proprioceptors in man. Neurophysiology, 1993, 25: 86–92. [CrossRef]
4) Karnath HO, Sievering D, Fetter M: The interactive contribution of neck muscle proprioception and vestibular stimulation to subjective "straight ahead" orientation in man. Exp Brain Res, 1994, 101: 140–146. [Medline] [CrossRef]
5) Bove M, Courtine G, Schieppati M: Neck muscle vibration and spatial orientation during stepping in place in humans. J Neurophysiol, 2002, 88: 2232–2241. [Medline] [CrossRef]
6) Lennerstrand G, Han Y, Velay JL: Properties of eye movements induced by activation of neck muscle proprioceptors. Graefes Arch Clin Exp Ophthalmol, 1996, 234: 703–709. [Medline] [CrossRef]
7) Kulkarni V, Chandy MJ, Babu KS: Quantitative study of muscle spindles in suboccipital muscles of human foetuses. Neurol India, 2001, 49: 355–359. [Medline]
8) Morizono T: Influence of neck vibration on body sway. Nippon Jibiinkoka Gakkai Kaiho, 1991, 94: 938–948. [Medline] [CrossRef]
9) Popov K, Lekhel H, Bronstein A, et al.: Postural responses to vibration of

neck muscles in patients with unilateral vestibular lesions. Neurosci Lett, 1996, 214: 202–204. [Medline] [CrossRef]
10) Yagi T, Yahima H, Sukuma A, et al.: Influence of vibration to the neck, trunk and lower extremity muscles on equilibrium in normal subjects and patients with unilateral labyrinthine dysfunction. Acta Otolaryngol, 2000, 120: 182–186. [Medline] [CrossRef]
11) Kasai T, Yahagi S, Shimura K: Effect of vibration-induced postural illusion on anticipatory postural adjustment of voluntary arm movement in standing humans. Gait Posture, 2002, 15: 94–100. [Medline] [CrossRef]
12) Verrel J, Cuisinier R, Lindenberger U, et al.: Local and global effects of neck muscle vibration during stabilization of upright standing. Exp Brain Res, 2011, 210: 313–324. [Medline] [CrossRef]
13) Taylor JL, Butler JE, Gandevia SC: Changes in muscle afferents, motoneurons and motor drive during muscle fatigue. Eur J Appl Physiol, 2000, 83: 106–115. [Medline] [CrossRef]
14) Gosselin G, Rassoulian H, Brown I: Effects of neck extensor muscles fatigue on balance. Clin Biomech (Bristol, Avon), 2004, 19: 473–479. [Medline] [CrossRef]
15) Schieppati M, Mardone A, Schmid M: Neck muscle fatigue affects postural control in man. Neuroscience, 2003, 121: 277–285. [Medline] [CrossRef]
16) Schmid M, Schieppati M: Neck muscle fatigue and spatial orientation during stepping in place in humans. J Appl Physiol, 2005, 99: 141–153. [Medline] [CrossRef]
17) Vuillerme N, Pinsault N, Vaillant J: Postural control during quiet standing following cervical muscular fatigue: effects of changes in sensory inputs. Neurosci Lett, 2005, 378: 135–139. [Medline] [CrossRef]
18) Darques JL, Jammes Y: Fatigue-induced changes in group IV muscle afferent activity: differences between high- and low-frequency electrically induced fatigues. Brain Res, 1997, 750: 147–154. [Medline] [CrossRef]
19) Carpenter JE, Blasier RB, Pellizzon GG: The effects of muscle fatigue on shoulder joint position sense. Am J Sports Med, 1998, 26: 262–265. [Medline]
20) Taimela S, Kankaanpaa M, Luoto S: The effect of lumbar fatigue on the ability to sense a change in lumbar position. A controlled study. Spine (Phila Pa 1976), 1999, 24: 1322–1327.
21) Isableu B, Ohlmann T, Cremieux J, et al.: Selection of spatial frame of reference and postural control variability. Exp Brain Res, 1997, 114: 584–589. [Medline] [CrossRef]
22) Isableu B, Cremieux J, Amblard B: Differential approach to strategies of segmental stabilisation in postural control. Exp Brain Res, 2003, 150: 208–221. [Medline]
23) Grod JP, Diakow PR: Effect of neck pain on verticality perception: a cohort study. Arch Phys Med Rehabil, 2002, 83: 412–415. [Medline] [CrossRef]
24) Bagust J, Rix GD, Hurst HC: Use of a computer rod and frame (CRAF) test to assess errors in the perception of visual vertical in a clinical setting e a pilot study. Clin Chiropr, 2005, 8: 134–139. [CrossRef]
25) Docherty S, Schärer R, Bagust J, et al.: Perception of subjective visual vertical and horizontal in patients with chronic neck pain: a cross-sectional observational study. Man Ther, 2012, 17: 133–138. [Medline] [CrossRef]
26) Falla D, Rainoldi A, Merletti R, et al.: Myoelectric manifestations of sternocleidomastoid and anterior scalene muscle fatigue in chronic neck pain patients. Clin Neurophysiol, 2003, 114: 488–495. [Medline] [CrossRef]
27) Kallenberg LA, Schulte E, Disselhorst-Klug C, et al.: Myoelectric manifestations of fatigue at low contraction levels in subjects with and without chronic pain. J Electromyogr Kinesiol, 2007, 17: 264–274. [Medline] [CrossRef]
28) Lee H, Nicholson LL, Adams RD: Neck muscle endurance, self-report, and range of motion data from subjects with treated and untreated neck pain. J Manipulative Physiol Ther, 2005, 28: 25–32. [Medline] [CrossRef]
29) Sommerich CM, McGlothlin JD, Marras WS: Occupational risk factors associated with soft tissue disorders of the shoulder: a review of recent investigations in the literature. Ergonomics, 1993, 36: 697–717. [Medline] [CrossRef]
30) Järvholm U, Palmerud G, Herberts P, et al.: Intramuscular pressure and electromyography in the supraspinatus muscle at shoulder abduction. Clin Orthop Relat Res, 1989, 245: 102–109. [Medline]
31) Jensen BR, Jorgensen K, Huijing PA: Soft tissue architecture and intramuscular pressure in the shoulder region. Eur J Morphol, 1995, 33: 205–220. [Medline]
32) Janwantanakul P, Pensir P, Jiamjarasrangsri V, et al.: Prevalence of self-reported musculoskeletal symptoms among office workers. Occup Med (Lond), 2008, 58: 436–438. [Medline] [CrossRef]
33) Cho CY, Hwang YS, Cherng RJ: Musculoskeletal symptoms and associated risk factors among office workers with high workload computer use. J Manipulative Physiol Ther, 2012, http://dx.doi.org/10/1016/j.jmpt.2012.07.004.
34) Abrahamová D, Hlavacka F: Age-related changes of human balance during quiet stance. Physiol Res, 2008, 57: 957–964. [Medline]
35) Faraldo-García A, Santos-Perez S, Crujeiras-Casais R, et al.: Influence of age and gender in the sensory analysis of balance control. Eur Arch Otorhinolaryngol, 2012, 269: 673–677. [Medline] [CrossRef]
36) Low Choy NL, Brauer SG, Nitz JC: Age-related changes in strength and somatosensation during midlife: rationale for targeted preventive intervention programs. Ann N Y Acad Sci, 2007, 1114: 180–193. [Medline] [CrossRef]
37) Cram JR, Kasman GS, Holtz J: Electrode placements. In: Introduction to surface electromyography. Gaithersburg: Aspen Publishers Inc, 1998, pp 269–271.
38) McIlroy WE, Maki BE: Preferred placement of the feet during quiet stance: development of a standardized foot placement for balance testing. Clin Biomech (Bristol, Avon), 1997, 12: 66–70. [Medline] [CrossRef]
39) Jørgensen K, Fallentin N, Krogh-Lund C, et al.: Electromyography and fatigue during prolonged, low-level static contractions. Eur J Appl Physiol Occup Physiol, 1988, 57: 316–321. [Medline] [CrossRef]
40) Moritani T, Muro M, Nagata A: Intramuscular and surface electromyogram changes during muscle fatigue. J Appl Physiol, 1986, 60: 1179–1185. [Medline]
41) Stapley PJ, Toffola ED, Schieppati M: Neck muscle fatigue and postural control in patients with whiplash injury. Clin Neurophysiol, 2006, 117: 610–622. [Medline] [CrossRef]
42) Taylor JL, Mccloskey DI: Illusion of head and visual target displacement induced by vibration of neck muscles. Brain, 1991, 114: 755–759. [Medline] [CrossRef]
43) Kavounoudias A, Gilhodes JC, Roll R, et al.: From balance regulation to body orientation: two goals for muscle proprioceptive information processing? Exp Brain Res, 1999, 124: 80–88. [Medline] [CrossRef]
44) Koskimies K, Sutinen P, Aalto H, et al.: Postural stability, neck proprioception and tension neck. Acta Otolaryngol Suppl, 1997, 529: 95–97. [Medline] [CrossRef]
45) Ljubisavljević M, Anastasijevic R: Fusimotor system in muscle fatigue. J Peripher Nerv Syst, 1996, 1: 83–96. [Medline]
46) Gatev P, Thomas S, Kepple T, et al.: Feedforward ankle strategy of balance during quiet stance in adults. J Physiol, 1999, 1(514(Pt3): 915–928.
47) Brauer SG, Burns YR, Galley P: A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. J Gerontol A Biol Sci Med Sci, 2000, 55: M469–M476. [Medline] [CrossRef]
48) Lord SR, Rogers MW, Howland A, et al.: Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc, 1999, 47: 1077–1081. [Medline]
49) Maki BE, Edmondstone MA, McIlroy WE: Age-related differences in laterally directed compensatory stepping behavior. J Gerontol A Biol Sci Med Sci, 2000, 55: M270–M277. [Medline] [CrossRef]
50) Anastasopoulos D, Bronstein A, Haslwanter T, et al.: The role of somatosensory input for the perception of verticality. Ann N Y Acad Sci, 1999, 871: 379–383. [Medline] [CrossRef]
51) Baier B, Suchan J, Karnath HO, et al.: Neural correlates of disturbed perception of verticality. Neurology, 2012, 78: 728–735. [Medline] [CrossRef]
52) Bronstein AM: The interaction of otolith and proprioceptive information in the perception of verticality. The effects of labyrinthine and CNS disease. Ann N Y Acad Sci, 1999, 871: 324–333. [Medline] [CrossRef]
53) Saj A, Honore J, Bernati T, et al.: Subjective visual vertical in pitch and roll in right hemispheric stroke. Stroke, 2005a, 36: 588–591. [Medline] [CrossRef]
54) Guerraz M, Yardley L, Bertholon P, et al.: Visual vertigo: symptom assessment, spatial orientation and postural control. Brain, 2001, 124: 1646–1656. [Medline] [CrossRef]
55) Barnsley L, Lord S, Bogduk N: Whiplash injury. Pain, 1994, 58: 283–307. [Medline] [CrossRef]
56) Bovim G, Schrader H, Sand T: Neck pain in the general population. Spine (Phila Pa 1976), 1994, 19: 1307–1309.
57) Schüldt K, Ekholm J, Harms-Ringdahl K, et al.: Effects of changes in sitting work posture on static neck and shoulder muscle activity. Ergonomics, 1986, 29: 1525–1537. [Medline] [CrossRef]
58) Hall C, Brody LT: Impairment in muscle performance. In: Therapeutic exercise moving toward function. Maryland: Lippincott William & Wilkins, 2005, pp 57–86.