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Impaired body balance control in adults with strabismus

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ABSTRACT

Previous studies revealed that people with binocular vision disorders have poor postural stability. However, most of the research was performed only on children and under binocular viewing condition, that could negatively affect the results. The aim of the current study was to investigate the influence of extra-ocular proprioceptive signals on postural stability in young adults with binocular vision disorders. Moreover, additional mental task was introduced to detect any postural compensation which could possibly hide the real influence of afferent extra-ocular signals.

21 Subjects, aged 18–45 yrs, with horizontal strabismus, were qualified to binocular vision disorders (B_{VD}) group. 41 subjects, aged 19–45 yrs, with no strabismus formed the normal binocular vision (N_{BV}) group. Posturography data were collected in 2 separate parts: (1) quiet standing (Single-Task), and (2) performance of a mental task while standing (Dual-Task). Each part consisted of three 60-s viewing conditions, with: (1) dominant/fellow eye (DE), (2) non-dominant/strabismic eye (NDE), and with (3) both eyes closed (EC). Subjects were looking at X located at the distance of 150 cm.

Generally, BVD group showed elevated body balance during quiet stance compared to NBV group. Interestingly, better stabilization in BVD group occurred under NDE viewing. Surprisingly, additional mental task improved the postural stability in BVD group almost to the level of NBV group. These findings emphasize the role of the eye-muscle signals in postural control and suggest that suitable vision therapy can be the appropriate way to improve body balance/motor functions in people with binocular vision disorders.

1. Introduction

Maintenance of postural stability is a multi-sensoral process which needs constant transformation of signals from the vestibular, somatosensory and visual systems (Brandt, Paulus, & Straube, 1986; Kapoula & Bucci, 2007; Matheron et al., 2007; Michalak, Przekoracka-Krawczyk, Nawrot, Woźniak, & Vieregge; ., unpublished data). Of these systems, the Romberg quotient shows that the visual one is most crucial in postural control since in normal subjects the sway area is 2–3 times larger with eyes closed than with eyes open (Edwards, 1946; Henriksson et al., 1967; Travis, 1945).

Gentaz (1988) suggested that one eye is usually more efficient in postural control, the so-called “postural eye” (not necessarily the dominant eye) allows for even better stability than when viewed binocularly. In some studies (Brandt, Paulus, & Straube, 1986; Kapoula & Bucci, 2007; Lê & Kapoula, 2006; Paulus et al., 1989), postural stability has been found to be impaired when the distance between eyes and the target increases due to a decrement of the angular size of retinal slip that makes it harder to detect. Another visual phenomenon to affect body equilibrium is motion parallax, that is relative motion of a far vs. a near object caused by body sway. This motion parallax has a positive influence on postural stability in both monocular and binocular viewing (Guerraz et al., 2001, 2000). What is more, Lê and Kapoula (2006) concluded that together with retinal slip and motion parallax, efferent signals (motor commands, top-down signals) and afferent signals (proprioceptive extra-ocular motor, bottom-up signals) from extra-ocular muscles related to vergence of the eyes, are also involved in postural stability. Convergence seems to significantly reinforce posture stability, which was shown in the studies on dyslexia (Kapoula & Bucci, 2007), strabismus (Gaertner et al., 2013a, 2013b) and interestingly, this effect is observed even with bilateral loss of vestibular function (Kapoula et al., 2013). It is commonly known that extra-ocular muscles have several proprioceptive receptors that provide information about the position of the eye in its orbit (Buisseret, 1995; Steinbach, 1987). Various studies (Brandt, Paulus, & Straube, 1986; Glasauer et al., 2005; Kapoula & Lê, 2006; Strupp et al., 2003) have shown that these signals affect

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postural control. Roll and Roll (1988) and Roll, Vedel, and Roll (1989) observed that vibration of individual extra-ocular muscles induce body sway significantly in the direction by stimulated muscles. Fox (1990) also stressed the role of proprioceptive signals from eye-muscles in postural stability. He found that in the dark, the body-sway was lower with both eyes open than with both eyes closed in quiet stance. This was explained by the influence of extra-ocular muscle tonicity on body balance control.

Legrand et al. (2011) reported that strabismus surgery is able to modify the quality of proprioceptive signals from extra-ocular muscles resulting in enhanced body stabilization. This occured even when binocular vision is not complete. Besides, Bucci et al. (2009) revealed that even non-strabismic children with abnormal vergence showed weaker postural stability compared to normal. This was explained as being from poor vergence input and/or immature compensatory mechanisms controlling postural stability (vestibular, somatosensory inputs or/and cerebellar processes).

The role of visual signals in body balance has been thoroughly investigated in strabismic children (Bronstein, 1995; Gentaz, 1991; Odenrick, Sandsted, & Lennerstrand, 1984). These studies indicated that strabismus influenced postural impairment. However, most of the studies aimed at comparing postural signals in strabismic subjects and normals were performed with both eyes open (Gaertner et al., 2013a; Legrand et al., 2011; Matsuo et al., 2006, 2010). Recently, Gaertner et al. (2013b) showed that in strabismic children, the effect of distance on posture depends on the direction of strabismic angle: the fixation depth at which postural stability was best was proximal for convergent strabismus and distal for divergent strabismus. The effort to overcome diplopia or vergence effort necessary to keep clear single vision could influence the center of pressure (CoP) excursions. Besides, as some strabismic subjects could have gross peripheral binocular vision (Gaertner et al., 2013b), the posture stability would be better due to peripheral cues from the strabismic eye (Amblard & Carblanc, 1980; Berencsi, Ishihara, & Imanaka, 2005). Thus, the separation of specific retinal and muscular signals from non-specific visual information (as diplopia or confusion) could appear difficult.

The aim of the current study was to investigate the influence of specific monocular oculomotor information on postural stability in young adults with binocular vision disorders (B_{VD} group). If the information from extra-ocular muscles is an important factor in postural stability, the B_{VD} group should exhibit significantly weaker body balance under both monocular viewing condition and with eyes closed (closing one's eyes does not eliminate proprioceptive signals related to eye muscle tension) (Matsuo et al., 2006). A posturography platform was used to evaluate the CoP excursions. Posturography was performed under monocular and eyes-closed condition to avoid the influence of destabilizing factors like diplopia, blurred vision or eyestrain caused by increased effort to maintain single clear vision under binocular viewing condition. It is important to note that we use a term extra-ocular muscle signals in our study, without distinguishing it between afferent or efferent signals, since it is not possible to judge which of them mainly influenced posturography results.

Since binocular vision deficits most often develop in childhood and adolescence, adults may have developed compensatory mechanisms (Bucci et al., 2009). As Friedrich et al. (2008) revealed, when the visual information is insufficient, compensation mechanisms such as vestibular, somatosensory and cerebellar processes can be activated to reach correct body balance. Furthermore, Peterka (2002) suggested, that if one sensory input is deficient, the other subsystem may compensate for the impairment through greater involvement in postural stability. Such compensatory mechanisms could hide the real influence of inadequate oculomotor signals on body balance. Similar motor compensatory mechanisms have been observed in dyslexia (Nicolson & Fawcett, 1990, 1999). It is possible that compensatory mechanisms may develop in B_{VD} adults. Therefore in the second part of the experiment, additional mental task (auditory Letter-Task) was performed while measuring the posturographic signals.

2. Material and methods

2.1. Participants

Seventy-three young adults were recruited from optometry students and strabismic patients of Laboratory of the Vision Science and Optometry at Adam Mickiewicz University and Optics and Optometry Center of Adam Mickiewicz Foundation in Poznań. Based on a medical interview, all were healthy without neurological, vestibular, musculoskeletal or orthopedic diseases. None were dyslexic or receiving medications known to affect balance. A vision examination, with special emphasis on binocular vision functions, was performed on each individual. This included an: extensive history interview, ocular dominance (fixating via hole task), refractive error, monocular and binocular visual acuity at far distance (Snellen's letter chart) with and without optical correction, amplitude of accommodation (push-up test), and monocular and binocular accommodative facility (accommodative flipper ±2D). Binocular vision was evaluated by the following tests: alternating cover test with prism bar (angle of strabismus/phoria), fusional vergence ranges (prism bar base-in and base-out); pola mirror, cheiroscope, tranaglyphs (Bernell©, series 500), Worth 4 dot, red lens (level of suppression and fusion), Titmus stereotest (Stereo Optical©) for stereopsis. The Red-lens test was performed in 9 positions of gaze to detect any extra-ocular muscle paralysis. We also evaluated near point of convergence, and ocular fixation by direct ophthalmoscopy (Heine©) and a retinal correspondence using both the Hering-Bielschowsky after-image and Bagolini striated glasses test. The detailed instructions of listed procedures are included in the literature (Borish, 1970; Caloroso & Rouse, 1993; Griffin & Grisham, 2002).

After the evaluation of visual functions, participants were divided into 2 groups. Subjects with any ocular pathology, refractive amblyopia, accommodative dysfunction, eccentric fixation, history of eye-muscle surgery, vertical or paralytic deviation were rejected from the study:

(1) Binocular vision disorders group (B_{VD}) – A total of 21 subjects (16 females, 5 males) with an age range of 18–45 years (mean 28.2, SD 9.1) with binocular vision disorders in either the eso- or exo-direction were placed in the B_{VD} group. Thirteen subjects demonstrated manifest strabismus (3 of them with esotropia, 10 of them were exotropic) and eight showed latent strabismus (decompansated exophoria[1] $>10\Delta$ at near and $>4\Delta$ at far). Six of them suffered from constant and fifteen from intermittent eye-deviation. Mean visual acuity of the non-dominant/strabismic eye was 20/22 (SD 20/65), while the mean visual acuity of the dominant/fellow eye was 20/17 (SD 20/170). Some individuals with manifest strabismus had peripheral stereoacuity, while the mean stereopsis of latent strabismus subjects was not less than 50 s of arc. Table 1 presents the visual parameters of each strabismic subject.

(2) Normal binocular vision group (N_{BV}) – Forty-one subjects (28 females, 13 males) with an age range of 19–45 years (mean 24.4, SD 7.1) and monocular visual acuities in normal range (20/20 or better), stereoacuity of minimum 50 s. of arc,

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[1] Decompensated heterophoria – the kind of heterophoria which is accompanied by symptoms due to large angle of heterophoria or/and inadequate motor/sensory vergence fusional reserve (Griffin & Grisham, 2002; Millodot, 2000).