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Research article

Reeducation of vergence dynamics improves postural control

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HIGHLIGHTS

- The REMOBI method improved vergence latency and accuracy.
- Visual symptomatology & Mean Power Frequency of body sway decreased with reeducation.
- Before reeducation, the body sway was positively correlated with the visual symptomatology.
- Results demonstrate the reciprocal interactions between vergence and postural control.

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ABSTRACT

Introduction: The purpose was to investigate the effect of vergence reeducation on postural control, in subjects with isolated vergence disorders.
Material and methods: We studied the dynamics of vergence in 19 subjects (20–44 years old) using video-oculography (Eye See Cam). On the basis of orthoptic and symptomatology assessments, ten of the subjects were diagnosed for vergence disorders then vergence eye movements were reeducated with the REMOBI method (US8851669, 5 weekly sessions lasting for 35 min). Postural control was measured before and after reeducation, postural recording was done in upright stance (Dynaport), with both eyes closed or open and looking a visual target located at 2 m distance.
Results: After reeducation with REMOBI, the visual symptomatology faded away and the stereoacuity improved at least for some subjects; the vergence latency decreased significantly and the vergence accuracy increased significantly. In terms of posture, the Mean Power Frequency (MPF) of the body sway decreased significantly in both eyes open and eyes closed conditions. Considering all subjects together (i.e. healthy subjects and subjects with vergence disorders before the reeducation), the antero-posterior body sway (Root Mean Square A/P) was positively correlated with the visual symptomatology: the higher the visual symptomatology, the higher was the body sway.
Conclusion: The results bring evidence for synergy between the quality of vergence and the quality of postural control. They open a new research line that bridges the gap between neuroscience, ophthalmology-orthoptics and posturology.

1. Introduction

Every activity while sitting or standing upright implies an adjustment of our eye movements in the three dimensional space. Our eyes are converging or diverging to fixate either proximal or distal objects, at the same time accommodation or desaccomodation (i.e. release of the lens accommodation) is activated together with the pupil restriction or dilatation. This complex phenomenon of adjustment of our eyes in the three dimensional space is subtended by an extended neural network involving the occipital, parietal, frontal, cerebellar and brainstem areas controlling both vergence and accommodation commands; for recent reviews see Gamlin et al. [1] and Alvarez et al. [2,3]. Vergence is also important for postural control. Postural stability in quiet stance was found to be better when the eyes are converging at a near point than when they are fixating at a far point (1 m and beyond [4–6]). This was demonstrated for many populations of children [7–11], adults and seniors with and without pathologies [12–15].

Multiple hypothetical mechanisms can explain this influence of vergence on postural control. First, an attentional mechanism in line with theory of motor basis of visual attention introduced by Rizzolatti [16]: eye movements are linked with attention and we hypothesize this link is particularly strong for vergence eye move-

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ments. Indeed, Tzelepi et al. [17] in an EEG study have shown in humans a strong bilateral central and posterior activation prior the convergence eye movements, while for divergence the activation is more posterior. Second, during any type of eye movements and particularly during vergence eye movements efference copy of motor signals and proprioceptive signals from extraocular muscles are presumably integrated by the Central Nervous System and contribute to postural control. Recall that postural control requires multi-sensory integration of visual, oculomotor, vestibular, somesthetic and proprioceptive signals. On the other hand, there is also evidence that vergence is acting on vestibular function. Indeed, it has been observed [18–20] that the gain of vestibular function is depending upon the vergence angle. Indeed, in healthy, the gain of vestibular function increases as the eyes are converging. Serra et al. [18] showed that patients with vestibular dysfunctions have also difficulties with vergence. Finally, vergence could act on posture via the well documented physiological synergy between extraocular muscles and neck muscles. Indeed, André-Deshays et al. [21,22] have shown that the excentration of the eye from the front gaze primary position, while the head is still stationary causes discharge of neck muscles; during saccade eye movements the discharge of neck muscles is correlated with the movement of the eyes. More recently, Corneil et al. demonstrated a similar phenomenon in monkeys [23,24] and pointed out that discharge of neck muscles can even precede movement of the eyes [25]. More specifically to vergence eye movements, some authors [26,27] have also shown that vibration of splenii neck muscles accelerates accommodative vergence. Finally more recent studies deal with the link between accommodation of a prolonged working at near distance and EMG neck muscles activity [28–31].

Another important point is that dynamic vergence, that is the movement of vergence from near to far or vice-versa, has also a further beneficial effect on postural control: postural stability is better when the eyes are performing actively vergence eye movements than when they are fixating. Indeed, in several studies [10,11,13,32,33] comparison was made between postural stability while the subjects are fixating steadily a point that is proximal or distal versus condition in which the eyes are converging and diverging between two points displayed in depth. It has been shown systematically that postural stability is better when the eyes are dynamically converging or diverging between points in the depth rather than fixating. This was explained by the same mechanisms, which are an intensified attentional efference motor command and a spreading of proprioceptive signals from extraocular muscles to neck muscle activity and thereby improving postural control. Particularly the study by Kapoula et al. [13] concerned adults who had idiopathic and bilateral loss of vestibular function with a history of five years or more; at this stage, patients did not have oscillopsia. Yet, it was shown that vergence eye movements were largely deficient in such population; interestingly, even though their vergence eye movements were deficient, postural control was significantly better in the active vergence condition than when fixating steadily. All these studies provide convincing evidence that vergence and particularly active vergence eye movements contribute actively to improve the postural stability in quiet stance.

Vergence problems are very frequent nowadays; recent surveys report that about 38 percent of the population may experience problems of binocular vision and some of them are related to vergence inefficiency [34,35]. Symptoms of vergence dysfunctions can be multiple: visual stress, headaches, blur, double vision, somnolence, difficulty and problems of balance and equilibrium [10]. Methods for diagnosis of vergence disorders are mostly empirical, based on measurements of the nearest point of convergence (NPC) and measurements of the degree of visual disparity that can be fused by the patient, induced for instance with a bar of prisms: subject has to report when the target is seen double. Rehabilitation of vergence by orthoptists is done also empirically, mostly with pencil push-ups and exercises with bar of prisms. In the present study we used a novel technology called REMOBI (patent US 8851669) which is a visual-acoustic trapezoid display that allows to stimulate sequences of vergence eye movements in the real 3D space; importantly, as the targets are in the real 3D space they stimulate natural synergy of convergence or divergence eye movements together with accommodation or desaccommodation, respectively for near and far targets. The same device allows to rehabilitate vergence with a specific algorithm based on research, an algorithm called “vergence double-step protocol” [36] whose clinical efficacy has been demonstrated in students suffering from vergence disorders. The purpose of the present study is to investigate the effect of vergence rehabilitation on the quality of the postural control.

2. Material and methods

The investigation adhered to the tenets of the Declaration of Helsinki and was approved by the local human experimentation committee, the “Comité de Protection des Personnes” (CPP) Ile de France VI (No: 07035), Necker Hospital in Paris, France.

2.1. Preliminary orthoptic examination and subjects

First, a complete orthoptic examination was done: we measured the near point of convergence (NPC) when the subjects were looking the tip of a pen; the binocular vision was evaluated with the TNO random-dot stereo test and/or with the Titmus Fly test; the vergence amplitudes and heterophoria (latent misalignment of the eyes when an eye is covered), both were tested by an orthoptist with the use of prisms. The vergence amplitudes corresponds to the maximal values of the prisms for which the patient claims to be able to see single despite the double image induced by the prism. For all values of orthoptic tests, comparison was made with the standard normality criteria from von Noorden et al. [37]. Also, an assessment of symptomatology was performed using a standard questionnaire called the Convergence Insufficiency Symptom Survey (CISS) [38].

Nineteen subjects (10 males) were divided in two groups according to the preliminary orthoptic examination: a group of healthy and a group of subjects with vergence disorders, considering those who showed a CISS score >20/60 (N = 10) and at least two abnormal values in the above mentioned orthoptic tests. Normal orthoptic criteria being: NPC < 10 cm, stereoacuity threshold <60 arc seconds, a range of convergence measured with a prism from 15pD to 23 at far distance and from 18pD to 24 at near distance [37,39]. Population included students, mostly from a technical secondary school (Lycée Fresnel, Paris, France); except for two adults (38 and 44 years old) with vergence disorders referred by the service of occupational medicine (France Télévision, Paris, France).

2.2. Video-oculography for vergence test

Subjects sat in front of the trapezoid device called REMOBI (*REéducation de la MOtricité BInoculaire*), which was placed at eye level (see Fig. 1A). Stimuli of this visual display were red Light-Emitting Diodes (LEDs) displayed on isovergence arcs at different distances along the midsagittal planes (0°). LED characteristics were nominal frequency 626 nm, intensity 180mCd, and diameter 3 mm; adjacent to each LED is embedded a buzzer with the following characteristics: nominal frequency approximately 2048 Hz, sound pressure level ≥7 dB and diameter 12 mm. After a variable fixation period of 1200–1800 ms, the target LED was lit for 2000 ms. The fixation LED was switched off 200 ms after the onset of the target LED (overlap paradigm). The lighting of each LED (fixation or target) was accompanied by the corresponding sound buzzer for 100 ms. Such visual-acoustic stimulation aimed to reinforce deployment of