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Postural control after traumatic brain injury in patients with neuro-ophthalmic deficits

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ABSTRACT

Postural instability is a common and devastating consequence of traumatic brain injury (TBI). The majority of TBI patients also suffer from neuro-ophthalmic deficits that can be an important contributing element to their sensation of vertigo and dizziness. Static posturography aims at the objective evaluation of patient balance impairment, but is usually affected by large inter- and intra-subject variability. Here we propose a protocol based on 10 randomized trials stimulating in different ways the visual and vestibular systems. Due to its completeness, our protocol highlights the specific residual difficulties of each patient in the various conditions. In this way, it was possible to evidence significant balance abnormalities in TBI patients with respect to controls. Moreover, by means of a multivariate analysis we were able to discriminate different levels of residual neuro-ophthalmic impairment.

1. Introduction

Traumatic brain injury (TBI) is an important cause of disability at all ages [1]. In the USA the annual incidence of emergency department visits and hospital admission are respectively 403 per 100,000 and 85 per 100,000 [2]. The mean annual incidence rate of hospitalized and fatal TBI for Europe is 235 per 100,000 [3]. Approximately 80% of injuries are classified as mild, 10% as moderate, and 10% as severe [3]. Severity is usually described by the Glasgow Coma Scale (GCS) [4], and is evaluated when the patient enters the emergency department. However, GCS may change during hospitalization and it does not describe the nature and the entity of the residual impairments. One of the most common complaints among TBI patients is postural instability and balance impairment [5,6].

Neuro-ophthalmic deficits commonly follow TBI, since the afferent and efferent pathways are vulnerable to traumatic injury. Commonly described categories of oculomotor dysfunctions are anomalies of accommodation, version, vergence (nonstrabismic, as well as strabismic), photosensitivity, visual field integrity, and ocular health [7]. Authors indicate different percentages of neuro-ophthalmic impairments following TBI, ranging from 39% to 90%, as described in [8–11].

Neuro-ophthalmic deficits may have important consequences on balance, since postural control integrates information from the visual, vestibular, and somatosensory systems.

Subjective complaints of dizziness that occur in the absence of objective clinical signs are difficult to assess [12,13]. Static stabilometry may provide an objective evaluation of postural instability [14–18] by characterizing the performance of the postural control system during quiet standing.

This technique is based on the study of the trajectories of the Center of Pressure (CoP) on the support surface. CoP trajectories are recorded by a force platform and analyzed using different techniques and extracting different kinds of parameters [16,18]. A possible limit of static stabilometry was highlighted by Ref. [15,19] due to the high inter-subject and intra-subject variability that many studies report.

Previous studies [12,13,20–25] addressed the problem of quantifying the consequences of TBI on balance assessment using static stabilometry. None of the studies published in the past specifically considered a group of TBI patients with a significant residual visual impairment.

Studies on static posturography are usually based on an acquisition protocol consisting of two trials, with open and closed eyes, respectively, to take into account the role of the visual system.

Our study differs from the previous ones in two aspects. First, we consider a group of TBI patients with residual neuro-ophthalmic deficits. Secondly, this study is based on a more complete acquisition protocol that adds to frontal open- and closed-eye trials, trials in which quiet standing of the subject is

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evaluated after a fast or a slow head rotation. In this way, it is possible to highlight the specific difficulties of each patient in various conditions that stimulate the visual and vestibular systems.

The aim of this study is to present a more complete acquisition protocol that allows to evaluate balance impairments in TBI patients and to demonstrate that such protocol can discriminate between controls and patients. Furthermore, we demonstrate that the presented protocol can also distinguish patients with different levels of visual impairment.

2. Materials and methods

2.1. Subjects

TBI patients were recruited from the outpatients of the Clinica Oculistica "C. Sperino", Ospedale Oftalmico (Torino), Italy, where they were referred for a neuro-ophthalmologic examination. On an average, 73% of approximately 70 TBI patients that were referred to Clinica Sperino in a year had neuro-ophthalmic impairments. The assessment of the severity of trauma was based on patient's history and medical records obtained from the Post-traumatic Rehabilitation Center of Caraglio (Cuneo, Italy) where they were treated after the injury. Our greater sample was formed by 50 subjects. The inclusion criteria were the typology of brain injury, its localization, and the presence of visual impairment only at the time of the test. We considered patients whose injuries were localized in the frontal, fronto-temporal, and fronto-temporo-parietal lobe, to select subjects with a high probability of suffering from neuro-ophthalmic deficits caused by the trauma. We excluded patients who showed residual sensorimotor or vestibular impairments. Thus, 13 TBI patients out of 50 were included in this study. These were four females (age 28–41 years, mean 34.5 $\pm$ 6.0 years; height 160–170 cm, mean 163.0 $\pm$ 4.8 cm; weight 53–85 kg, mean 62.5 $\pm$ 15.1 kg) and nine males (age 22–63 years, mean 33.7 $\pm$ 13.9 years; height 170–186 cm, mean 181.0 $\pm$ 3.4 cm; weight 70–90 kg, mean 79.0 $\pm$ 6.4 kg). Table 1 shows patient's characteristics.

The control group consisted of 43 healthy subjects, 26 females and 17 males, matched for age, height and body mass index, with no orthopedic, neurological or visual problems.

Both TBI patients and controls underwent a neuro-ophthalmologic examination prior to the test to evaluate the visual system. They were examined for pupillary reflex, smooth pursuit, saccades and optokinetic nystagmus. The last column of Table 1 reports the clinical evaluation of the residual visual impairment at the time of the balance test. In all patients abnormal saccades were observed. In five patients global deficits of the eyes version were found. These patients were classified as "severe" in the last column of Table 1. Three patients showed both saccades and smooth pursuit anomalies and were classified as "moderate". Patients in which only abnormal saccades were observed were classified as "mild". All the subjects belonging to the control group did not show any neuro-ophthalmologic abnormality.

The experimental protocol was approved by the local ethical committee and all participants gave their written informed consent to the study.

2.2. Acquisition protocol

Subjects were asked to stand quietly, in upright position, over a Kistler 9286A force platform. The inter-malleolar distance was fixed at 4 cm and the feet opening angle was 30°. The acquisition protocol consisted of 10 different trial conditions, five with eyes open (looking at a visual target) and five with eyes closed. The head positions were: (1) frontal: open eyes frontal (OEF), closed eyes frontal (CEF), (2) head rotated after a slow left rotation: open eyes left slow (OELs), closed eyes left slow (CELs), (3) head rotated after a slow right rotation: open eyes right slow (OERs), closed eyes right slow (CERs), (4) head rotated after a fast left rotation: open eyes left fast (OELf), closed eyes left fast (CELf), (5) head rotated after a fast right rotation: open eyes right fast (OERf), closed eyes right fast (CERf). At the operator order, the subject reached the requested head position and then the signal acquisition started. A biaxial accelerometer fixed on the forehead of the subject was employed for monitoring the head rotation. Each recording started at the end of the head rotation and lasted for 60 s.

The sequence of trials was randomized to avoid learning and/or fatigue effects [26]. For every two trials the subject rested for 1 min moving away from the platform.

The platform signal was recorded with a sampling frequency of 2 kHz and then down-sampled to 50 Hz. The acquisition system was Step32 (DemItalia, Italy).

2.3. Data analysis

We calculated the major geometrical and time-domain parameters based on the CoP trajectory [16,17]. Table 2 describes the set of parameters we considered.

First, we compared TBI and controls—for each trial condition and CoP parameter—by means of a two-sample *t*-test, after verifying the gaussianity of the distributions.

Moreover, we were interested taking into account the inter-relations among CoP parameters in the different trials, using the global information arising from the complete protocol: for each subject we have a total of 70 dependent variables (10 trials $\times$ 7 parameter values). To this purpose, we applied a multivariate analysis of variance (MANOVA) approach [27–29]. We reduced the number of CoP parameters considered, preserving those containing non-redundant information and discarding parameters highly correlated among them or with high within-group variability. To select the reduced set of parameters we used Wilks' Lambda statistic (Λ) [27]. Λ is an index of the parameters' discrimination capability. It is defined as the ratio between the within-groups generalized variability and the total generalized variability, the latter being the sum of the within-groups and between groups generalized variability. This index takes values between zero and one, lower Λ-values indicating a better discrimination among groups.

The procedure we adopted is the following. As a first step, we calculated Λ for each parameter separately and sorted the parameters in Λ ascending order. We kept the parameter with lower Λ-value. Then we considered all the possible combinations of two parameters, recalculated the corresponding Λ-values and sorted them in ascending order, keeping the combination with lower Λ-value. The process was carried out iteratively adding one parameter at a time, each time recalculating the Λ-value and choosing the combination of parameters showing the lowest Λ-value. The parameter selection stopped when, adding more parameters, Λ did not significantly decrease [27].

After the selection of the reduced set of CoP parameters we summarized the information arising from the 10-trial protocol applying a canonical variate analysis (CVA) [27]. The canonical variables C are linear combinations of the original variables, chosen to maximize the separation among groups. Specifically, the first canonical variable $C1$ is the linear combination of the original variables that has the maximum separation among groups. This means that among all possible linear combinations, it is the one with the most significant F statistic in a one-way analysis of variance. The second canonical variable $C2$ has the maximum separation while being orthogonal to $C1$, and so on. We represented the two populations of TBI and controls in the plane of the first two canonical variables.

Table 1
Characteristics of traumatic brain injury patients.

Patient	Age (years)	Gender (M/F)	GCS score[a]	CT/MRI	Time (months)[b]	Cause	Residual damage[c]
1	26	M	15	Negative	37	Violence	Mild
2	62	M	14	Positive	130	Traffic accident	Moderate
3	25	M	4	Positive	35	Fall from scaffolding	Severe
4	41	F	8	Positive	42	Traffic accident	Severe
5	28	M	8	Positive	95	Traffic accident	Severe
6	31	M	6	Positive	71	Traffic accident	Severe
7	22	M	Not available	Positive	55	Traffic accident	Mild
8	28	F	9	Positive	64	Fall from horse	Severe
9	31	F	8	Positive	38	Traffic accident	Mild
10	38	F	6	Positive	66	Traffic accident	Moderate
11	38	M	6	Positive	143	Traffic accident	Mild
12	21	M	14	Positive	15	Traffic accident	Mild
13	50	M	14	Positive	17	Fall from scaffolding	Moderate

[a] Lowest Glasgow Coma Scale score after hospitalization.
[b] Time elapsed from head trauma.
[c] Assessed from the clinical neuro-ophthalmic evaluation of the patients prior to the balance test.