How a predictive analysis can be used to assess which hemiparetic patients can gain advantage from additional visual feedback of center-of-pressure displacements?

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Abstract. Past studies have emphasized that hemiparetic stroke patients do not always take advantage from additional visual feedback (VFB) of center-of-pressure displacements in undisturbed upright stance. This study was designed to assess the best parameters (area and variances along medio-lateral and antero-posterior axes of the center-of-pressure displacements) that could predict this capacity to take advantage from VFB and to identify the patients who would be capable of positively using it to improve balance control. The postural behaviors of thirty-nine patients were recorded. Patients were evaluated in two randomly experimental conditions (eyes open with and without additional visual feedback). A predictive analysis was computed to evaluate the interest of using the VFB during rehabilitation through the knowledge of positive and negative predictive values. Lateral instability (mediolateral variance of the center-of-pressure displacements), the main postural deficiency in hemiparetic patients, was the most efficient parameter for predicting the consequences of using VFB postural control. Patients with a low mediolateral variance do not have benefit from VFB technique for stance rehabilitation. The less stable hemiparetic patients, characterized in our case by medio-lateral variances superior to a 23 mm² threshold, gain advantage to VFB technique. The decision of when to provide or not this additional sensory information could be relevant in order to optimize the balance rehabilitation protocols.

Key words: Stroke, posture, visual feedback, predictive value

Résumé. Comment une analyse prédictive permet de répertorier les patients hémiparétiques susceptibles de tirer bénéfice d'un feedback visuel additionnel des déplacements de leur centre des pressions ?

Des études antérieures ont montré que les patients hémiparétiques ne tiraient pas toujours bénéfice d’un feedback visuel additionnel (VFB) des déplacements de leur centre-des-pressions (CP) en station debout non-perturbée. Cette étude a pour but d’identifier les paramètres permettant de prédire cette capacité et les patients qui pourraient utiliser cette information pour améliorer le contrôle de leur équilibre. Trente-neuf patients ont été évalués au travers de deux conditions réalisées selon un ordre aléatoire (yeux ouverts avec ou sans feedback visuel additionnel). Une analyse prédictive a été ensuite réalisée afin d’évaluer l’intérêt de la technique du VFB dans le domaine de la réhabilitation au travers de valeurs prédictives positives et négatives. L’instabilité latérale (appréciable par la variance des déplacements medio-latéraux du CP), principal déficit postural chez ces patients, apparaît être le paramètre le plus discriminant pour prédire les conséquences d’un contrôle postural avec VFB. Il ressort que les patients avec une variance médio-latérale faible de leur CP ne tirent pas réellement bénéfice de la technique du VFB pour récupérer leur équilibre. Les patients hémiparétiques les plus instables, caractérisés dans notre cas par des déplacements medio-latéraux de leur CP excédant une valeur seuil de 23 mm², sont à même de tirer un bénéfice immédiat de la technique du VFB. Des règles de décision quant à l’utilisation de cette information sensorielle supplémentaire pourraient permettre d’optimiser les protocoles de rééducation de l’équilibre.

Mots clés : Accident vasculaire cérébral, posture, rétroaction visuelle, valeur prédictive
1 Introduction

After stroke, patients generally display balance disorders during upright standing, which in turn induce impaired gait. Even though clinical scores are extensively used to assess its performance, postural control can be easily and objectively assessed from force platform (Dickstein, Nissan, Pillar, et Scheer, 1984). In particular, several outcomes can be computed from the center-of-pressure (CP) displacements. Hemiparetic patients are traditionally characterized by reduced loading on the paretic leg and, compared with healthy subjects, by a greater postural instability (Rode, Tiliket & Boisson, 1997). A comparison of the CP displacements occurring along mediolateral (ML) and anteroposterior (AP) axes indicate that the ML control is impaired in hemiparetic patients (Genthon, et al., 2008). This specificity stems from the incapacity of the nonparetic leg to compensate for the larger CP displacements intervening under the paretic leg and the larger involvement of the nonparetic leg in the production of the CP displacements. A return of these parameters closer to their initial values can be considered a main objective during rehabilitation.

Additional visual feedback (VFB) of CP displacements, which consist in displaying on a monitor the CP displacements issued from the force platform on which the individual stands, is one of the most frequently used rehabilitation tools. Whereas some studies considered VFB as was recently shown (Rougier & Boudrahem, 2010). If this latter study was able to differentiate among subjects those who can take advantage from those unable to decrease their postural movements, the reported data however cannot be used to make any prediction based on a standardized postural scores. The decision of when to provide or not this additional sensory information could be relevant in order to optimize the balance rehabilitation protocols.

In this view, a predictive analysis seems to be an appropriate way to target patients with or without the ability to gain advantage from VFB. In particular, one may also question whether bi-directional area or unidirectional variance along ML and AP axes are equally able to establish the discrimination of the beneficiaries. Therefore, the purpose of the present investigation, was to identify i) the best parameters that could predict the ability of these patients to use the VFB technique, and ii) the patients who would be capable of positively using VFB information to improve their balance control. To this aim, the force platform data recorded in a past study (Rougier & Boudrahem, 2010) for characterizing the VFB effects in hemiparetic patients, were re-used.

2 Material and methods

2.1 Subjects

The study included 39 patients with a recent first hemispheric stroke (15 women, 24 men; age 61.8 ± 11.4 ; mean ± SD) years, days from onset 92.8 ± 55.6 years from neurological and orthopaedic disorders. All patients were able to stand quietly unaided over 60 s with their eyes open. The severity of the patients’ motor and sensory impairment was assessed by means of a standardized neurological examination. Extrapersonal spatial awareness was assessed using the bells tests (32.41 ± 2.99/36; maximal score; Gauthier, Dehaut, & Joanette, 1989). The tactile sense of the paretic side was assessed based on the patients’ ability to discriminate prick and touch at the pulp of the big toe (0.77 ± 0.48/2). The spasticity of 5 muscles of the lower limbs was also measured using the Ashworth scale (5.85 ± 3.39/25; Bokannong & Smith, 1987). Postural capacity during daily life and functional independence were assessed using the Postural Assessment Scale for Stroke (PASS) (30.54 ± 2.99/36) and Functional Independence Measure (FIM) (99.13 ± 15.32/126) scores, respectively. Clinical characteristics correspond to those usually observed in series of patients with a degree of recovery compatible with upright standing maintenance without help for several minutes after a stroke of various size and location. Stoke patients were eligible if they had normal visual acuity and contrast sensitivity. As required by the Helsinki declaration, all healthy and disabled subjects gave informed consent in accordance with the guidelines of the local ethics committee.

2.2 Postural assessment

The ability to maintain the standing posture was assessed by posturography using a force platform (PF01, Equi+, France). The patients were asked to stand quietly as stable as possible, barefoot, in a standardized position with their feet placed on marks (heels separated by 3 cm, toes out at 30°), arms hanging freely along the body, with their eyes open in two randomized experimental conditions separated by a seated period lasting 5 min (Rougier & Boudrahem, 2010). For each condition, five trials lasting 64 s separated by rest period of 1 min, during which the patients remain upright, were recorded. Whereas no additional instruction was given for the eyes open (EO) condition, the main requirement of the VFB condition was to reduce as much as possible the spot movements, displaying the CP displacements, on a screen positioned in front of them. A practice trial was always performed before the measurements to ensure that the subjects had mastered the relationship between their body motions and the displayed spot movements. The standing patients were accompanied by the investigator, who stood beside them and was ready to intervene if necessary.
Fig. 1. Predictive analysis method. 1) Illustration of the problem: how do we know whether subjects should be included in category X (non-dependant subjects) or Y (dependents subjects) on the basis of a known parameter (PP)? 2) Distribution of a sample of analyzed subjects in a predictive table. a and c are the numbers of category X subjects with a PP value below and above a threshold, respectively; b and d are the numbers of category Y subjects with a PP value below and above a threshold, respectively. The chosen threshold is those with which the Youden index is maximal. 3) Positive and negative predictive values are computed on the basis of the predictive table obtained with the threshold previously determined. It is hypothesized that the more unstable the subjects, the greater their dependency on VFB.

The upright quiet stance was quantified by classically used parameters such as area (CP-area, mm²), and the variance (amplitude) of the CP movements along the ML and AP axes (Var-CP-ML, mm², and Var-CP-AP, mm², respectively).

2.3 Assessment of the influence of VFB on postural control

As previously described (Rougier & Boudrahem, 2010) the influence of VFB on postural control was quantified through a dependency coefficient (DC) enables to assess the impact of visual information, computed from results of both EO and VFB conditions, and whose principle is close to the classic Romberg coefficient (Lacour, et al., 1997).

DC = (EOscore - VFBscore) / (EOscore + VFBscore)

A positive and negative ratio indicates that patients use the VFB positively and negatively, respectively. This coefficient, which does not require any associated probability since applied on individuals, was computed to all the postural parameters studied.

2.4 Predictive analysis

Prediction analysis is widely used in clinical biology to assess the diagnostic performances of laboratory tests. However, only few studies have used this tool in the rehabilitation field of hemiparetic patients (Guillebastre, et al., 2011; Kollen, Kwakkel, & Lindeman, 2006; Rabadi & Blau, 2005). The prediction analysis consists to set apart patients from their results, in relation to a threshold, obtained in a known parameter. Since our objectives were to determine for each parameter the threshold value inducing the most efficient predictive test as well as to compare these tests, the Youden index (Youden, 1950) was used (ranged between −1 and 1, the latter being the strongest). Figure 1 details the successive steps of the prediction analysis. For the present study, positive (PPV) and negative (NPV) predictive values correspond to the probability of the subjects using the VFB negatively and positively when the parameter value was below and above the threshold, respectively.
Table 1. Predictive values. The Positive and Negative Predictive Values (PPV and NPV, respectively) are the probabilities of patients with a lateral instability below or above the threshold using the VFB negatively (negative dependency coefficient) or positively (positive dependency coefficient), respectively. Note that the threshold value is the same (23 mm) to predict the impairments (without non-significant differences) or improvements (with significant differences) of postural parameters during the VFB condition compared with the eyes-open one. Significance level was set at $p < 0.05$.

<table>
<thead>
<tr>
<th>Postural parameters</th>
<th>VFB effects</th>
<th>Min</th>
<th>23</th>
<th>Max</th>
<th>Negative using of VFB information</th>
<th>Positive using of VFB information</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP-area (mm$^2$)</td>
<td>VFB</td>
<td>185.9 ± 106.2</td>
<td>206.5 ± 137.4</td>
<td>p value</td>
<td>0.283</td>
<td>752.3 ± 469.9</td>
</tr>
<tr>
<td>Var-CP-ML (mm)</td>
<td>VFB</td>
<td>8.8 ± 5.2</td>
<td>10.7 ± 8.9</td>
<td>p value</td>
<td>0.195</td>
<td>67.0 ± 55.7</td>
</tr>
<tr>
<td>Var-CP-AP (mm)</td>
<td>VFB</td>
<td>19.3 ± 11.9</td>
<td>21.2 ± 13.1</td>
<td>p value</td>
<td>0.293</td>
<td>44.6 ± 21.5</td>
</tr>
</tbody>
</table>

2.5 Statistical analysis

Since all postural parameters of patients were demonstrated to be Gaussian (using Kolmogorov-Smirnov tests), paired Student t-tests were computed to assess the VFB effects with a first significance level set at $P < 0.05$.

3 Results

3.1 Efficiency of postural parameters for predicting the VFB effects

Youden index values indicate the efficiency of all postural parameters in predicting the sign of dependency coefficients (DC) of each parameter. Therefore, lateral stability (i.e., variance along the ML axis) was found to be the most efficient parameter for realizing this prediction. Indeed, to predict the sign of the CP-area DC, Youden index values were 0.53 for CP-area, 0.59 for Var-CP-ML and 0.43 for Var-CP-AP. To predict the sign of the Var-CP-ML DC, Youden index values were 0.52 for CP-area, 0.55 for Var-CP-ML and 0.47 for Var-CP-AP. Finally, to predict the sign of the Var-CP-AP DC, Youden index values were 0.62 for CP-area, 0.65 for Var-CP-ML and 0.46 for Var-CP-AP.

3.2 Effects of VFB information on patients’ postural control

Table 1 shows the results obtained through the predictive analysis. Patients with a variance in CP along the ML axis below 23 mm used the VFB technique negatively, resulting in negative DC values of CP-area (PPV: 52.6%), Var-CP-ML (PPV: 73.7%), and Var-CP-AP (PPV: 63.2%) parameters. However, for these patients, postural parameters were not significantly increased during the VFB condition, as compared to the EO condition. In addition, the patients with a variance along the ML axis exceeding 23 mm$^2$ used the VFB technique positively, resulting in positive DC values of CP-area (NPV: 95%), Var-CP-ML (NPV: 85%), and Var-CP-AP (NPV: 95%). Thus these patients significantly improved the studied postural parameters during the VFB condition as compared to the EO condition.

4 Discussion

To date, no consensus has been found on using the VFB technique to improve postural control. To clarify this question, our study aimed at identifying the parameters to be used for predicting the effects of VFB information in hemiparetic patients. The use of the predictive analysis method, described in our study, is considered as the gold standard to predict a behavior in the light of a known parameter. More precisely, this method allows identifying the best parameter which efficiently predicts a behavior, and categorizing subjects in relation to a threshold objectively determined. However, using this methodology in the rehabilitation field remains little-spread.

Lateral stability appears to be the most efficient postural parameter to predict effects of VFB information on postural control. Interestingly, the same threshold (23 mm$^2$) for the ML variance of CP displacements during EO condition provides strong predictive values for all studied parameters. Indeed, on one hand, patients above this threshold use the VFB positively (rate of certainty, 85%) to significantly enhance their postural control, particularly for a predominant impairment in these patients which is the instability along ML axis (Genthon, et al., 2008). On the other hand, most of the other patients use VFB information negatively without significant differences on postural parameters. As a result, using VFB to improve postural control turns out to be ineffective for patients with a lateral stability value below the threshold. However, one should keep in mind that using our
coefficient to characterize the notion of visual dependency remains quiet arbitrary. Indeed, patients who negatively use the VFB based on our dependency coefficient should also be able to occasionally positively use VFB information whereas only the general behavior is considered in our process.

We are aware that the threshold value obtained from this upright standing evaluation largely depends on numerous factors from the recording characteristics of the force platform and the protocol. For instance, modifying the lateral distance between the feet increases the base of support and generally induces a reduction of the CP movements and body motions along the ML axis (Day, Steiger, Thompson, Marsden, 1993). It is worth noting that the threshold value presented here applies only to specific conditions including visual information, feet positioning and instructions. Interestingly, the ability in hemiparetic patients to reduce variances along the ML axis constitutes a pre-requisite of the capacity to load the paretic side and therefore to load the body-weight unloading mechanisms which is recognized as a determining factor for independent gait and more generally autonomy (Guillebastre, et al., 2011). In addition, our results only provide information on the immediate effects induced by the VFB technique. Further research is therefore needed to analyze the longer-term effects. However, one may hypothesize that patients for whom short-term effects can be observed might more easily benefit from long-term training protocols. Finally, while posturography is rarely available in a clinical setting, the contribution of our results to the rehabilitation field may facilitate the generalization of this assessment.

In conclusion, since the effectiveness of VFB as a rehabilitation tool remains uncertain, our data provide an original insight: this technique should be useful for hemiparetic patients as long as their postural control impairment makes them unable to restrain their CP displacements along the ML axis in order to obtain a value below a given threshold. In our case, a variance of less than 23 mm² in the eyes open experimental condition would be the determining postural score.

Bibliography


