Title: Design of a mechatronic system for postural control analysis

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Abstract

Balance control is necessary to perform any basic activity in every day life. With aging, the skill of a person to keep balance is altered and can lead to serious hazards especially for elderly people, since falls represents the second leading cause of injury deaths worldwide. To assess the ability of a patient to keep or regain balance, posturographic analyses are performed in many clinical environments by skilled operators. A posturographic clinical test can be performed in a static (unperturbed) or in a dynamic (perturbed) condition. The definition of such perturbation is related to the desired outcome of the specific test to perform. For instance, recovery mechanisms are far more evident if a mechanical perturbation is exerted on the body of the subject. On the other hand, elderly people with a compromised physical condition might be not eligible for a test in perturbed condition. The multiplicity of solutions available regarding perturbation systems and of methodologies for the interpretation of postural responses represents the main reason for the lack of standard procedures in dynamic posturography. The possibility to exert different mechanical perturbations to the body of the subject, e.g. by shifting the base of support or directly applying pulling or pushing forces, leads to the wide scenario of solutions available. The selection of the mechanical interaction and of amplitude, direction, point of application of the stimuli represents the foundation for the design of any postural analysis systems. The aim of these systems is to identify significant correlations between single or multiple perturbations and the entity of the responses.

This work has the objective to present a novel system for postural perturbation, able to exert force stimuli directly to the body of a subject with predefined waveform, amplitude and duration. This perturbation must be scalable and adaptable. The former refers to the possibility to vary its amplitude in order to evoke responses with different entity. The scalability is also necessary to allow for testing subjects with different constitution and health conditions. Adaptability refers to the opportunity to select different points of application and directions of the stimuli. This feature is relevant to guarantee the unpredictability of perturbations. To improve usability, the perturbation device should be directly maneuvered by the operator by means of appropriate handles. The perturbation system must be eventually expandable to provide multiple stimuli at the same time. This feature can be comfortably achieved by design of simple perturbation devices, based on low cost and compact architectures, which can be eventually replicated and coordinated to perform simultaneously. Several prototypes of perturbation devices have been tested, and an experimental test-bench for the evaluation of different components and control solutions has been designed. An analytical model of the system has been developed and validated by trials performed in laboratory. The system, in its final architecture, has shown good accuracy and repeatability with high dynamics. The devices have been tested on different samples of healthy subjects, showing a relevant correlation between the impulse (time integral) of the contact force and the Center of Pressure displacement over the base of support that had not been reported earlier in the literature. The relationship between perturbation and response data has been discussed also by means of analytical modeling of postural control, that includes single and two-links inverted pendulum models as well as frequency domain techniques.