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POSTURAL CONTROL ANALYSIS USING ACTIVELY CONTROLLED STEWART PARALLEL PLATFORM

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SUMMARY

The main function of postural control is to provide upright posture of the body and to maintain the balance during the motion. In the event of an external perturbation, it alters the motion of the body to prevent the human from falling over. We propose a novel method of postural control analysis using a Stewart parallel platform. In comparison to the previous studies where the induced perturbations remained fixed for a period of time, the idea of our method is that when the perturbation of the posture occurs, the device that caused the perturbation allows the postural control to return the body to the original posture from before the occurrence of the perturbation. A typical trajectory of the angular displacement of the parallel platform is given where the myotatic reflex can be observed as well as the tolerance to the platform inclination after the compensation of the perturbation. Using a polar diagram of the maximal displacements of the centre of gravity in the directions of the perturbations, the directionality of the postural disturbance is presented.

INTRODUCTION

Postural control is one of the key elements of human locomotion. Its main function is to provide upright posture in the gravity field and to maintain the balance of the body during the motion. In the event of an unpredicted external perturbation, it alters the motion of the body segments to ensure the overall stability and prevents the human from falling over.

Previous studies investigated various aspects of postural control under perturbations. The perturbations were either limited in direction to the anteroposterior plane [1, 2, 3] or were induced in both anteroposterior and mediolateral planes [4, 5]. Common to all these investigations is that the induced perturbations were, in a mechanical sense, static. The perturbations were produced by either angular or linear displacement of the support surface at a certain unpredicted moment and then remained fixed for a period of time when the measurements of various biomechanical parameters were performed. Such static perturbations very accurately simulate real-world scenarios such as standing on a bus that is driving on a hilly road and the passengers have to stay balanced without the help of hands. The task of muscular activities induced by this kind of perturbations is to alter the relative positions of the segments of the human body in a way that it remains stable under the influence of the present perturbation. In the bus example, the muscles have to

change the posture of the passenger's body to remain balanced when the bus starts to drive uphill.

On the other hand, the static perturbations used by previous investigations are not an appropriate approximation of the real-world perturbations where the human is standing on a stable support and the posture is perturbed unexpectedly by external force-impulse acting on the human body. In this case the task of the postural control is not to adapt the posture to a changed support surface orientation, but to move the human body back into the stable posture that the body had before the occurrence of the perturbation.

Probably the most accurate simulation of such scenario would be to perturb the human posture by an actual physical push of a mechanical device such as a robotic manipulator on various locations of the human body and to measure the biomechanical responses of the human to these perturbations. However, if the visuomotor feedback of the human is not to be eliminated, than it would be very difficult to achieve the unpredictability of the perturbations performed in such manner.

As an alternative to this approach we propose a novel method of postural control analysis using an actively controlled Stewart parallel platform. Arguably, the proposed method faithfully simulates the real-world scenarios with stable support surface and force-impulse postural perturbations described above. Besides the design of the method, the purpose of this study was to perform a basic analysis of the human posture under the influence of the perturbations produced by the proposed method.

METHODS

The main idea of the proposed method is that when the perturbation of the posture occurs, the device that caused the perturbation allows the postural control to return the body to the original posture from before the occurrence of the perturbation. This way the muscle activities have an actual mechanical effect that is comparable to the muscular activities during the real-world perturbations. By the analysis of the centre of gravity trajectories we can then quantitatively evaluate the performance of the postural control under various conditions.

Figure 1 depicts a human subject standing on a force plate mounted at the top of the Stewart parallel platform. The parallel platform has the ability to arbitrarily translate in all

three directions and to rotate around all three axes of rotation. It is controlled by the motion controller implemented on a personal computer. The task of the perturbation generator is to generate the desired perturbations at random moments in time. The output of the perturbation generator is then summed with the displacements of the centre of gravity of the human subject recorded in real time using the force plate. Basically, motion of the parallel platform perturbs the posture by shifting the centre of gravity of the human subject. The postural control of the subject then reacts against the perturbation which also causes the motion of the centre of gravity. The displacement of the centre of gravity is feed to the motion controller which causes the parallel platform to move back to the initial state. As an effect, the postural control corrects the posture by moving the parallel platform beneath the feet of the human subject. The postural control can then be analyzed by the resulting motion of the parallel platform.

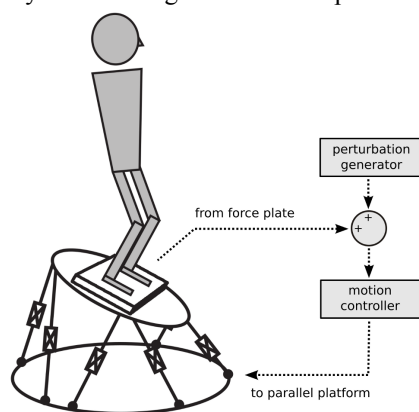


Figure 1: Experimental setup with a human subject standing on a force plate mounted at the top of the parallel platform. The platform is controlled by the motion controller which reacts to the perturbation generator and the centre of gravity data recorded by the force plate.

After the approval of National Medical Ethics Committee, 10 male subjects (age 27 ± 3 years; height 1.75 ± 0.05 m; mass 82 ± 6 kg) gave informed consent to participate in the study. During the trial, subjects were instructed to stand still on the platform with their feet together. The platform produced rotational perturbations in 12 directions around the vertical axis. The timing between the perturbations and their order was randomly selected. The platform rotated for 8.5 degrees with the maximal speed of 50 degrees per second. The motion of the parallel platform and the centre of gravity data were collected simultaneously at 100 Hz.

RESULTS AND DISCUSSION

Diagram on Figure 2 shows a typical trajectory of the parallel platform angular displacement (wiggly trajectory) during the occurrence of the perturbation (red square trajectory). Due to the angular perturbation of the platform, which causes stretching of ankle muscles, an occurrence of the myotatic reflex can be observed at about 100 ms after the rise of the perturbation at 5 s. Its counter efficiency can be clearly seen as a small notch on the trajectory [6, 7]. The diagram on Figure 2. also demonstrates a certain amount of tolerance to the platform inclination after the compensation of the perturbation at about 7.5 s. The platform displacement did not return to zero but remained at about 3 degrees. This

offset was observed with all directions of the perturbation around the vertical axis.

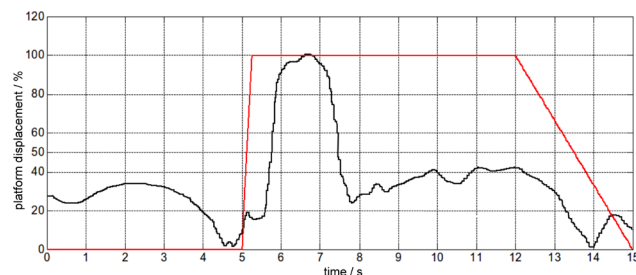


Figure 2: Trajectory of generated perturbation (red) and overall motion of parallel platform during perturbation.

To evaluate the efficiency of the postural control to the direction of the perturbation, we measured the maximal displacement of the centre of gravity in the direction of each perturbation. A polar diagram that shows these displacements together with the standard deviation area is presented on Figure 3. It is apparent that posture was much less disturbed by the perturbations in the anteroposterior direction than the perturbations in the mediolateral direction. This finding is not surprising and can be easily explained by the kinematics of the human body.

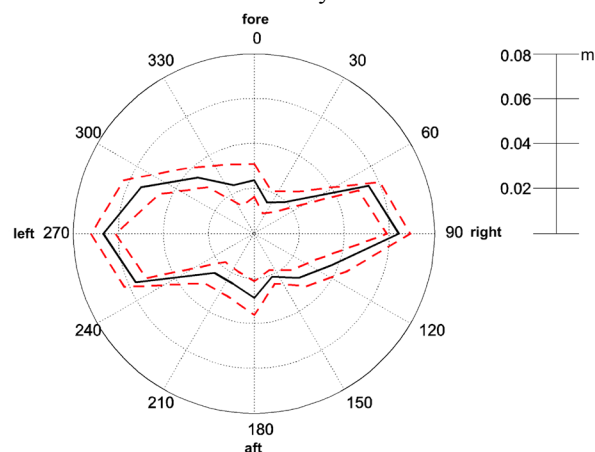


Figure 3: Maximal displacements of centre of gravity in directions of perturbations

CONCLUSIONS

In conclusion, we proposed a novel method of postural control analysis using an actively controlled Stewart parallel platform which faithfully simulates the real-world perturbations. We demonstrated the usefulness of a parallel platform in posture analysis and presented a basic analysis of the posture control under the angular perturbations in different directions.

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