Technical Report

Validation/Verification Testing of the B-Shoe in a Gait Laboratory

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The operation and performance of the B-Shoe (validation/verification testing) were tested in a Gait Laboratory under conditions that emulate imbalance and in situations where elderly people may fall. The laboratory is equipped with a moving platform on which test subjects stand. Imbalance conditions are generated by moving the platform floor while people are standing on it. The platform is capable of moving in 6 degrees of freedom, three translation motions in all directions and three rotations. A system of cameras tracks and analyzes the test subject's shoes and body responses in three dimensions. The platform is equipped with pressure sensors that provide information on the foot's position and the pressure forces it induces on the ground. The tests compare how people respond to imbalance when using normal shoes and the response while using the B-Shoes. Standard backward pull tests were also performed as normally done by Doctors that examine suffering patients.

The recording shows the translation perturbation generated by the platform in the forward and backward directions and the translation of the B-Shoe relative to the platform. The test also measured the position of the center of pressure of the B-Shoe on the floor. This reflected the sway of the person while trying to maintain stable standing. Addition plot shows the energy of the sway by calculating the square of the sway amplitude and averaging over time to smooth the instantaneous response.

Typical recording of a single test is given in the three figures below.

Top graph - The blue curve shows the platform motion, forward and backward (positive/negative). The red curve shows the B-Shoe motion relative to the platform and the green curve shows the vertical translation of the B-Shoe (when the foot was lifted).
Bottom graph - The blue curve shows the platform motion. The red curve shoe the center of the foot pressure on the platform and the magenta shows the energy of the sway.

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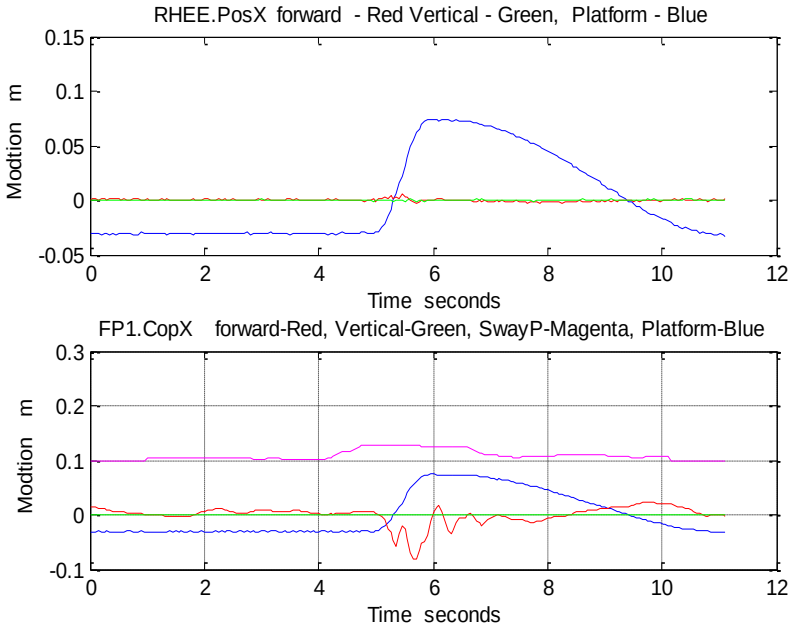
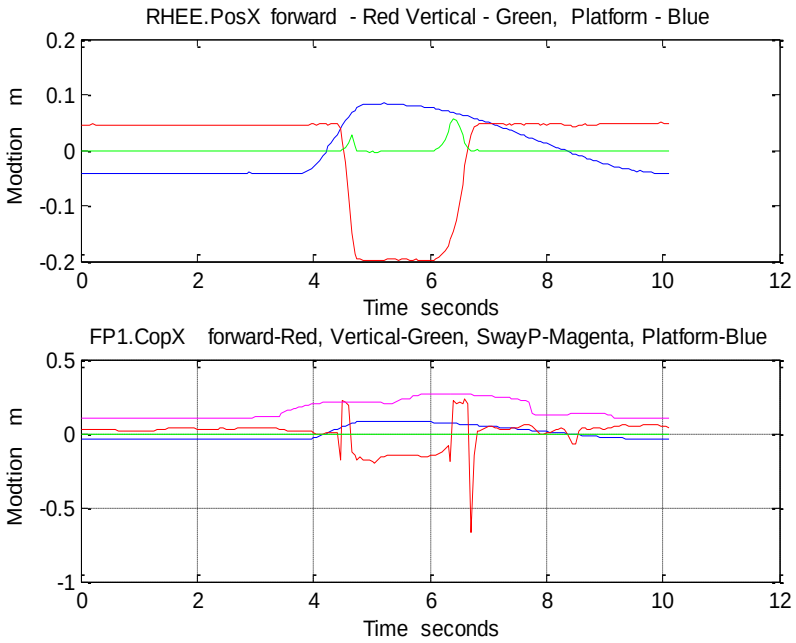
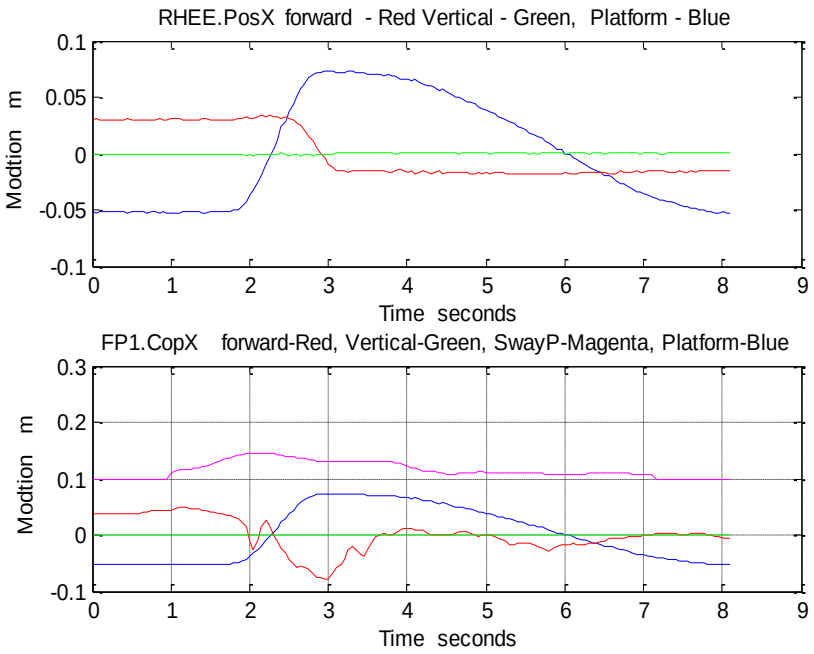
1) In the first case the B-Shoe was not enabled. The test subject was able to regain balance by moving his body and was not forced to execute a backward step to maintain his balance. The foot did not move from the floor and the sway was moderate.



2) In the second case the B-Shoe was not enabled but the test subject had to step backward (top red) to balance himself. Once he regained balance he executed an additional forward step to return to the original position. The top-green curve shows that the test subject lifted his foot from the platform to execute the backward step. The bottom-red curve demonstrate how the backward step shifts the center of pressure (center of support of the body) to assist in regaining balance. The sway was severe mostly due to the backward step.



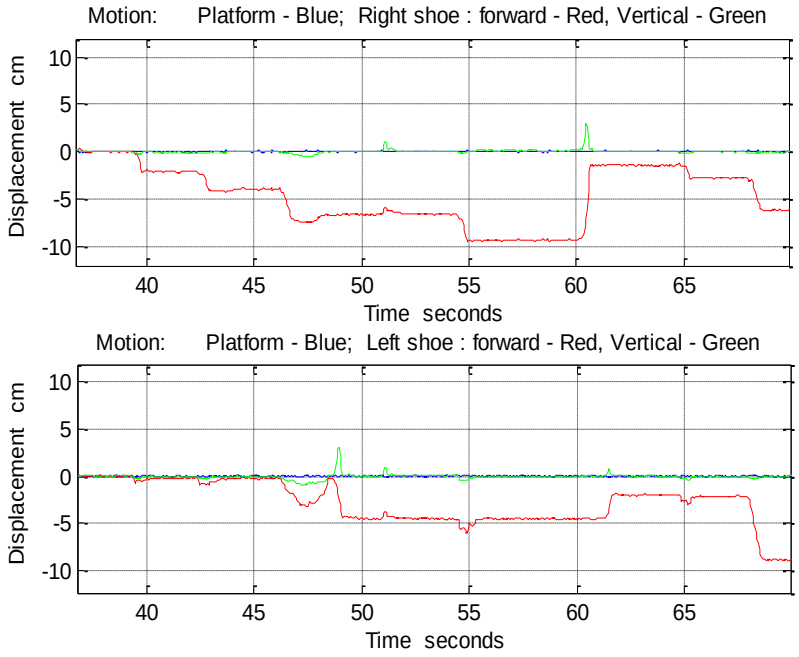
3) In the third case the B-Shoe was enabled and assisted the test subject to maintain balance. The B-Shoe traveled a distance of about 6 cm without lifting the foot from the ground. The top-red curve shows the B-Shoe backward traveling. This motion replaces the backward step. In the bottom-red curve the center of pressure shifted backward, but much less than the when a backward step was taken. A correction step forward was then unnecessary. The sway was less severe than when a backward step was taken.



A second test to evaluate the use of the B-Shoe and its operation was performed in a procedure called the "pull test". In this test another person stands behind the test subject and pull him backward in a random pulls. We have found that this procedure provided conditions that better represent loss of balance. In the platform test the test subjects were able to learn the platform motion, be alert and prepared themselves to the upcoming perturbations. They tend to either lean a little forward or flex their body to assist in the balance regaining phase. In the pull test the test subjects could not predict neither the timing nor the strength of the pull and could not prepare themselves. In this case they either executed the backward step or leaned back and let the B-Shoe roll back. They always initially leaned backward and if the pull was strong enough they also executed a backward step. This behavior always activated the B-Shoe's rolling.

When the B-Shoe was disabled the examinees almost always had to execute the backward steps to regain balance.

The figure below shows the B-Shoe motion in a series of moderate pull tests. The top curve shows the right foot and the bottom curve shows the left foot. The red curve is the forward/backward translation and the green curve is the vertical motion.



In this test the test subject was pulled back several times, each pull varying in intensity, but all where moderate pulls. Most of the correction was done with the right foot. Each time (39, 43 47, 54, 66, 68 seconds) the B-Shoe traveled a few centimeters to regain balance. At the 48 second mark the test subject lifted his left foot and executed a backward step in addition to the B-Shoe rolling. At the 61 second mark the test subject lifted his right foot to return the shoe to the original position.
The test subject used both B-Shoes to assist in regaining balance. Both B-Shoes were activated independently according to how much the test subject leaned backward on each foot. No confusion was seen by the use of both B-Shoes at the same time.

Conclusions

The test demonstrated the operation of the B-Shoe and the contribution to the person wearing it. The following observations were made:

- The B-Shoe replaces the need to execute a backward step to regain balance when the test subject leaned backward.
- If the sway backward was strong the test subject executed an additional backward step. There was no conflict between the B-Shoe operation and the necessity to add a backward step.
- Either one of the B-Shoes, right or left, can operate independently. There was no need for coordination of the two B-Shoe operations. No confusion was caused by the independent action.