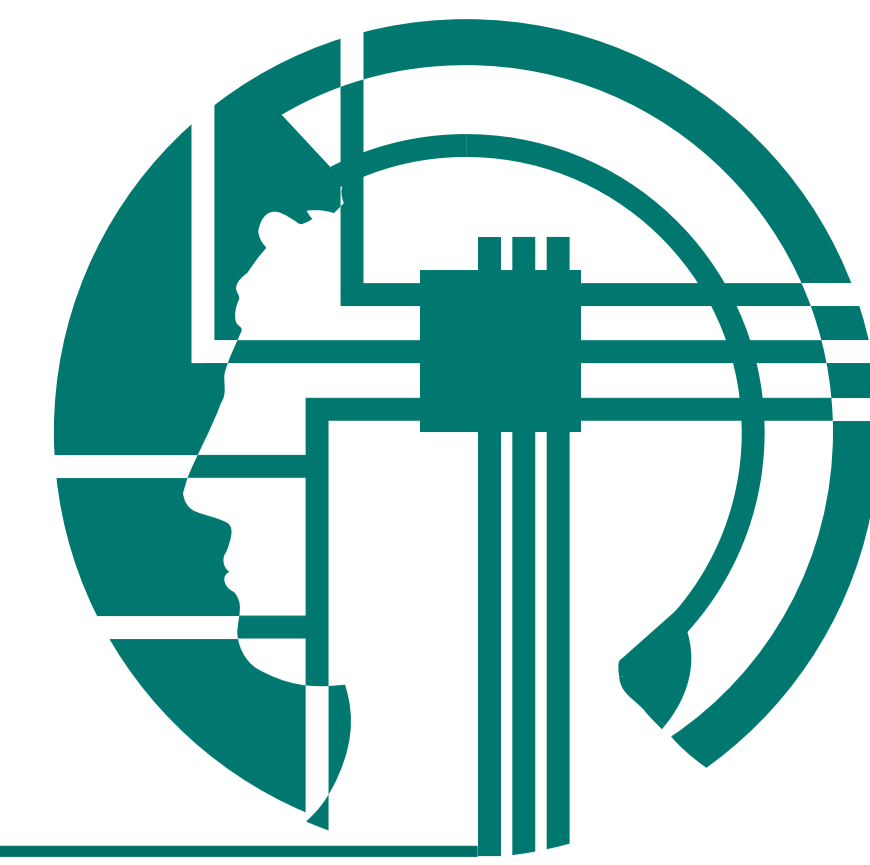




Stabilization of oneself in Virtual Reality: Interaction of visual and vestibular cues

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• Motivation

How are vestibular and visual systems integrated?

Is it possible to transfer a learned skill between the sensory modalities?

Although the different sensory organs have quite different characteristics, it seems that we have no problems in their combined evaluation. To study this evaluation we chose the task of self stabilization, which is a well known task used for standing, walking, or slow bicycle riding. To perform this task would most probably require more than one sensory system. We want to answer here the following questions:

- How do we evaluate the information that we get from the different sensory organs?
- Can we integrate these different types of information to improve our perception?
- Is it possible to transfer a learned skill from one modality to another?

• Equipment

We used a motion platform for the vestib. stim., a HMD for vis. stim and a joystick as input device.

For the following stabilization task humans mainly use the vestibular, visual, and proprioceptive senses. To study this sensor fusion in a body stabilization task, we used a motion platform with six degrees of freedom for the vestibular stimulus, a head mounted display (HMD) for the visual stimulus, and a joystick as an input device (see Fig. 1-3).



Figure 1: Head Mounted Display (HMD) for the visual stimulus.



Figure 2: Joystick as input device.



Figure 3: Motion platform with six degrees of freedom for the vestibular stimulus.

• Experimental Design

The simulation was based on an inverse pendulum.

The motion platform and the HMD simulated the physical model of an inverse pendulum. Using the joystick, the subject could exert a force (acceleration) on the pendulum and thereby control the state of the model (see Fig. 4).

For the roll and yaw axis the vis. stimulus was equivalent to the vestib. stimulus.

In our experiments, the subjects had to balance themselves on the pendulum against changes in roll, yaw, or both axes simultaneously. They had either vestibular information, visual information, or both. The visual stimulus was a random-dot cloud with limited life-time dots and an artificial horizon in order to match the character of the vestibular stimulus (absolute positional information for roll, but only information about changing of position for yaw).

There were pre- and post-tests and six training sessions inbetween. During the training, one half of the subjects were trained only visually the other only vestibularly.

Subject performed a pre-test, six training sessions, and a post-test. In the pre- and post-test sections, the subjects had to perform a stabilization task for all nine possible conditions. For the training section, the eight subjects were divided into two groups receiving only visual or only vestibular input (VISGroup and VESTGroup, respectively).

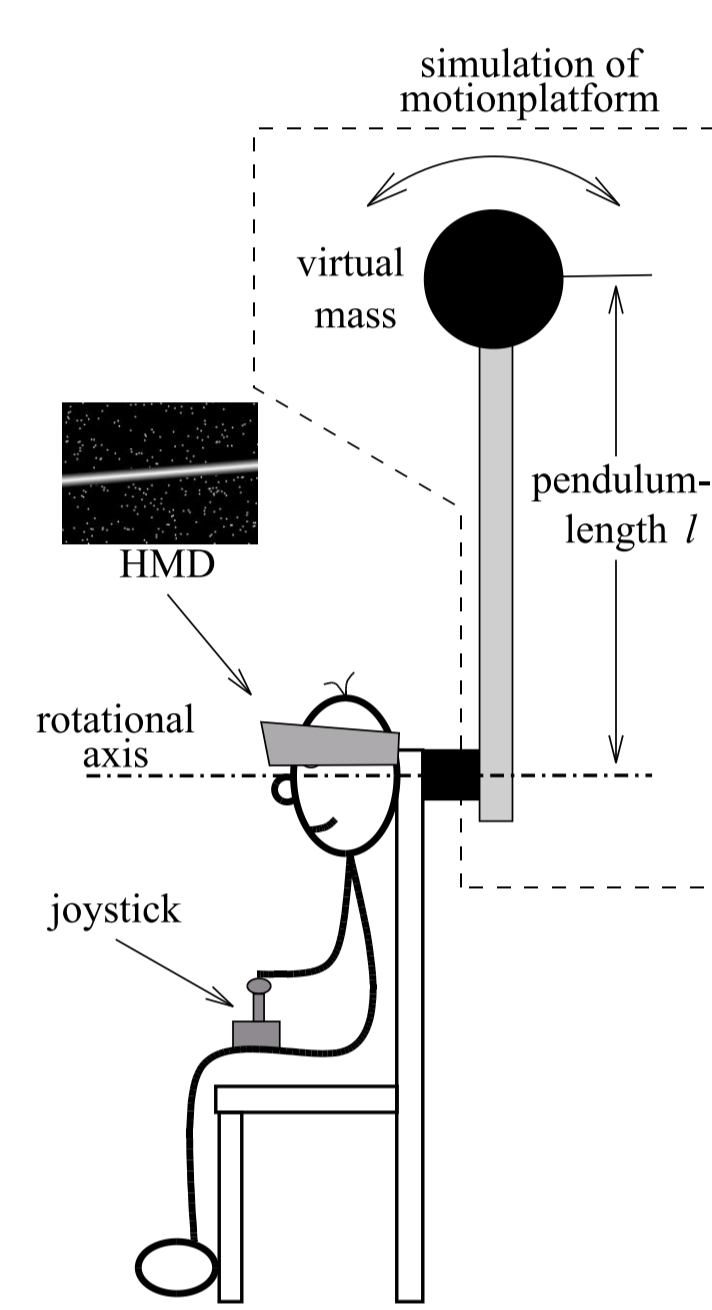


Figure 4: The principle of the stabilization task

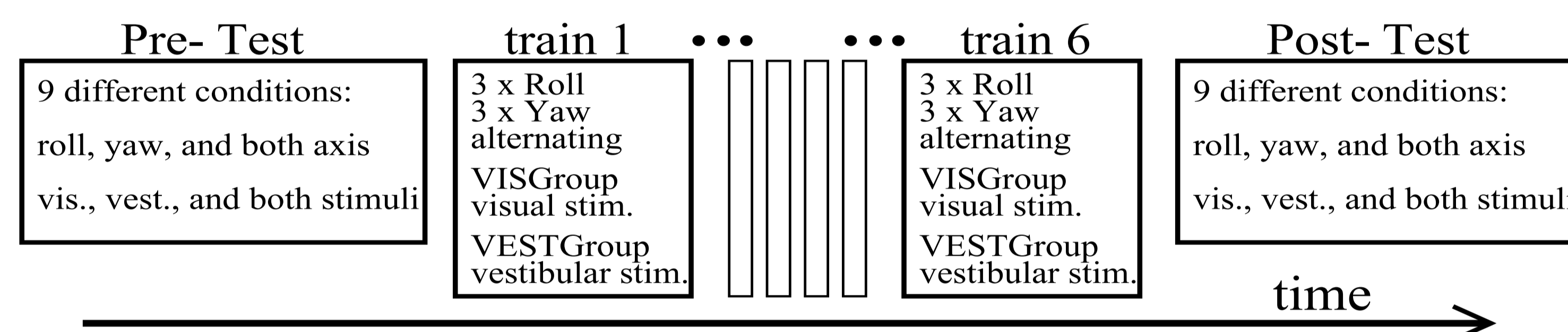


Figure 5: Experimental design

• Results

There is an overall training effect.

During the training section, the performance (the mean of the absolute positional error) of all subjects showed a large overall improvement. They improved their performance from pre- to post-test for the roll task and also for the yaw task (roll-task: pre-test 3.72°, post-test 2.16°, $t(7)=4.9$, $p<0.002$; yaw-task: pre-test 4.97°, post-test 3.67°, $t(7)=5.3$, $p<0.002$) (see Fig. 6).

Subjects in the yaw-task always perform best with visual stimulus.

In the pre- and post-test of the yaw stabilization task, subjects performance was much better with visual than with vestibular stimulus (pre-test: vestibular 6.89°, visual 3.83°, $t(7)=12.3$, $p<0.0001$; post-test: vestibular 5.85°, visual 2.27°, $t(7)=8.9$, $p<0.0001$) (see Fig. 7, right plot).

In the roll-task is a higher learning effect with vestib. than with vis. stimulus.

In the pre-test of the roll-task the performance of the subjects was significantly better with the visual than with the vestibular stimulus (vest. 4.97°, vis. 3.14°, $t(7)=5.0$, $p<0.002$) but this was not the case in the post-test. So, the subjects had a much higher increase in performance with the vestibular stimulus (vest. 1.44°, vis. 0.95° decrease of the average absolute position from pre- to post-test, $t(7)=2.9$, $p<0.023$) (see Fig. 7, left plot).

Transfer between the modalities seems to be possible.

Finally, the VESTGroup showed a significant improvement (the ratio of performance in the pre- and post-test) in the **visual** roll task (on average 40% increase of performance from post- to pre-test, $t(3)=4.6$, $p<0.02$). The VISGroup showed also a large but non-significant improvement in the **vestibular** roll task (on average 32%). This suggests that subjects are able to transfer their learned skill from one input modality to another (see Fig. 8).

• Conclusions

Subjects can determine position from rotational acceleration.

Subjects were able to do the yaw stabilization task in both modalities. This suggests that subjects can determine their position in space from the rotational acceleration.

The vis. modality is more intuitive than the vestib.

In the pre-test for the roll task, subject perform much worse with the vestibular stimulus than with the visual. This suggests that the evaluation of the data from the vestibular modality is much harder than the data from the visual system for humans.

No combined evaluation of different modalities.

Figure 7 shows no increase in performance when both signals were available at the same time. So we can not confirm any model for sensor fusion, which does a combined evaluation from vestibular and visual stimuli.

Transfer from vis. to vestib. modality.

For the roll task the visually trained group showed a significant increase of performance with vestibular stimulus. This suggest that the subject used the visually learned skill in the vestibular task, too.

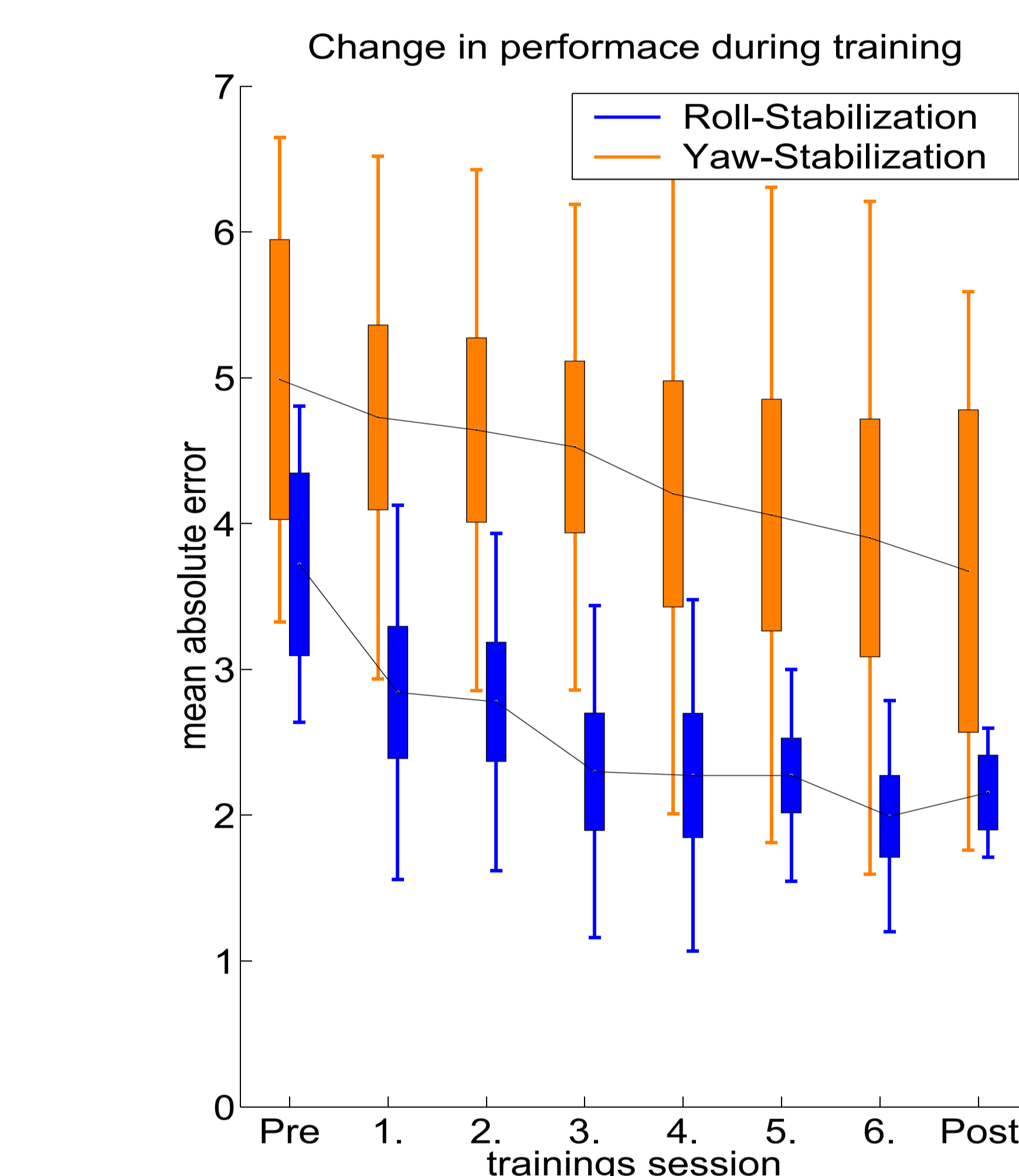


Figure 6: This graph shows the performance during the pre- and post-test and training sessions. The box plots are over all subjects during roll- and yaw-stabilization. The data of the pre- and post-test are with only one axes and one modality at the same time.

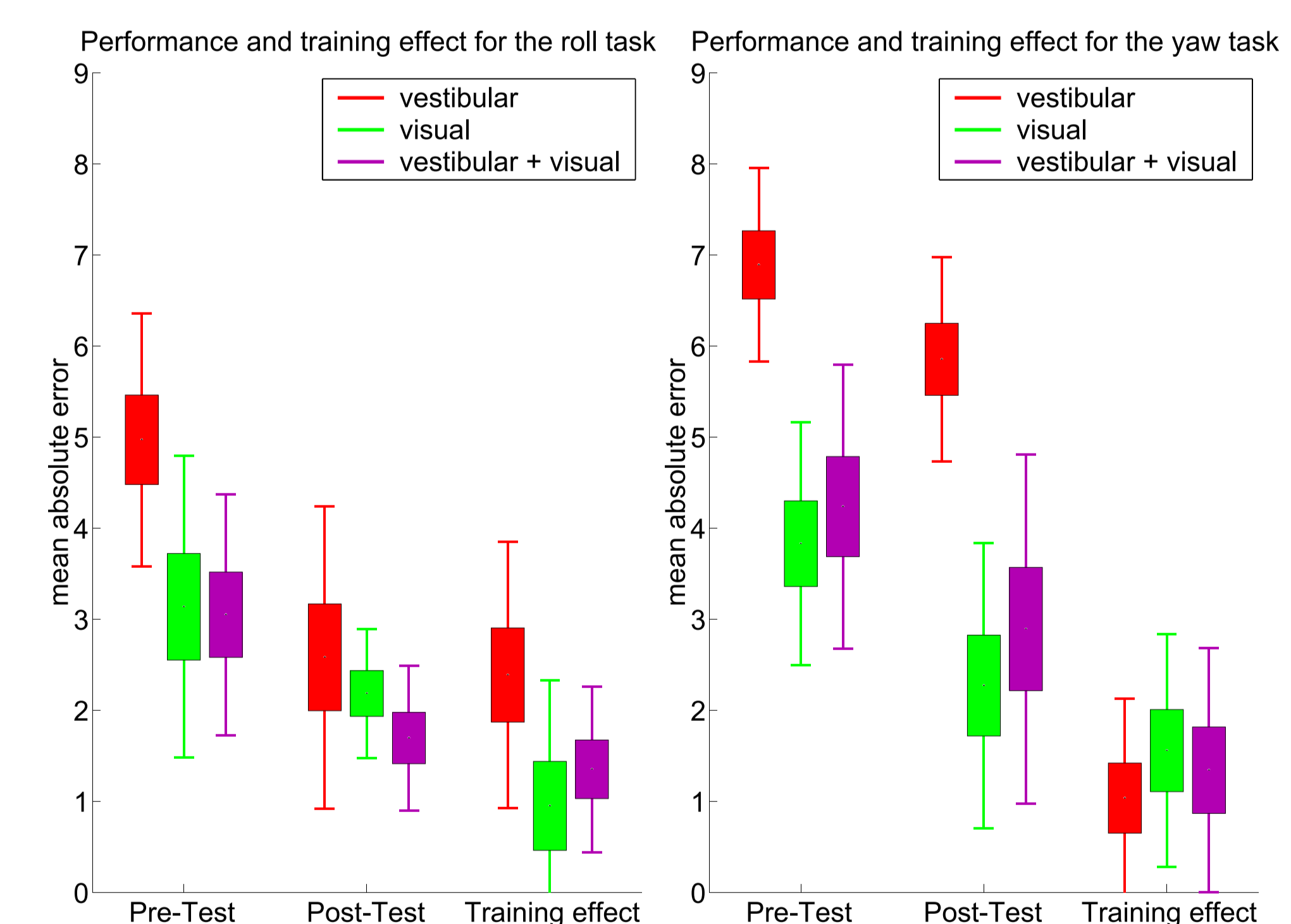


Figure 7: These two graphs show the performance of all subjects during pre- and post-tests with visual, vestibular, and both modalities. The left graph shows the performance for the roll-stabilization task and the right one for the yaw-stabilization task. The training effect is the difference in performance between the pre- and post-tests.

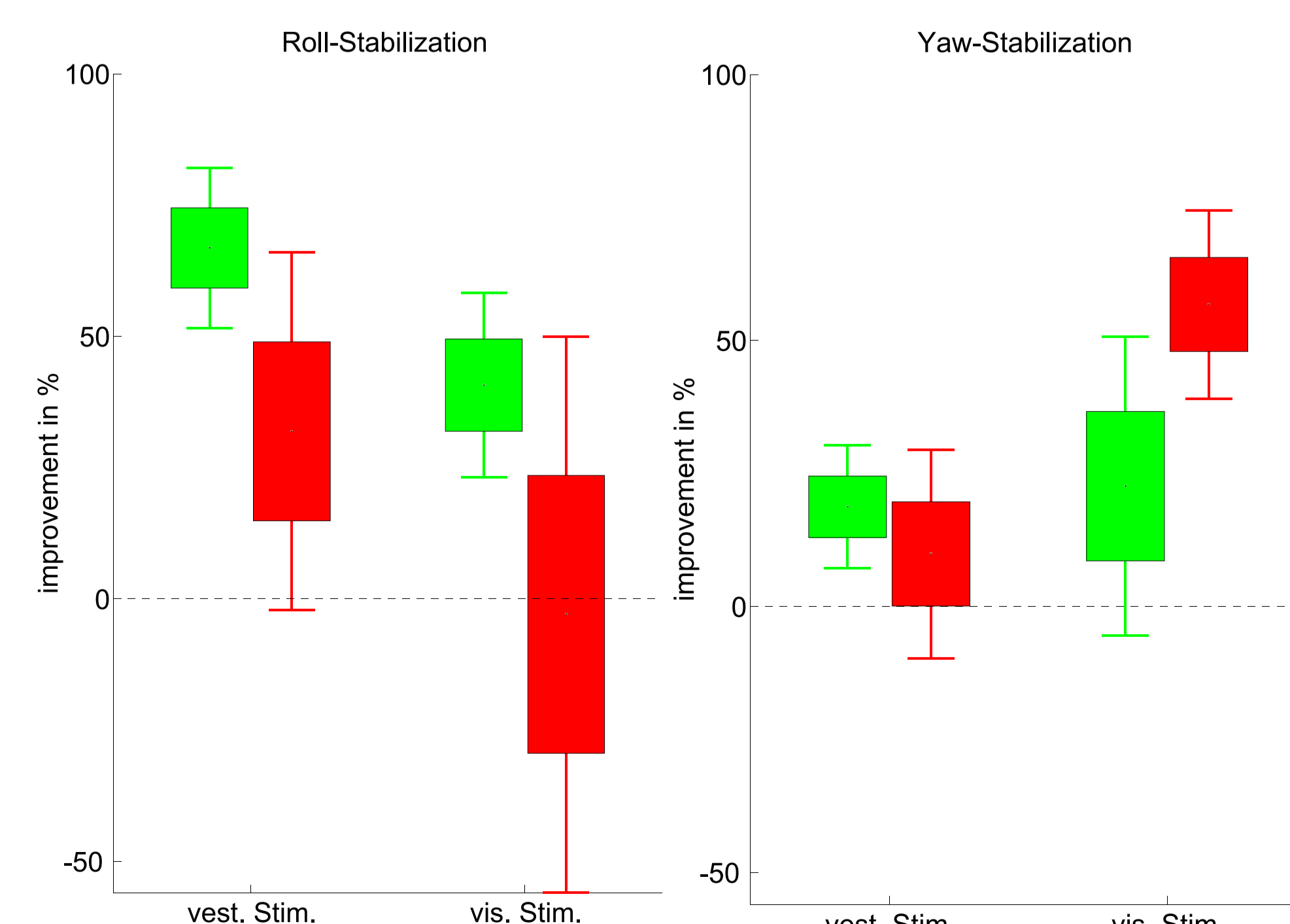


Figure 8: These two graphs show the change in performance for the roll- (left) and yaw-stabilization (right) for the vestibularly (VESTGroup) and visually trained groups (VISGroup). The improvement is the ratio of the performance in the post-test and pre-test for each subject.