# The Shaker: A Platform for Active Perturbations in Neuromechanical Studies of Small Animals

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**Abstract.** In this paper, we inform about the development of a three degrees of freedom active platform for neuromechanical experiments. This platform, termed 'the shaker', generates single or combined horizontal, vertical, and tilting perturbations with a payload up to 1 kg. It can produce horizontal and vertical perturbations with amplitudes up to 1 cm at oscillation frequencies up to 10 Hz. The tilting motions were constrained to 15°/s. The shaker can measure single ground reaction forces (GRF) using up to four custom-build force plates mounted on the platform. Preliminary experiments with rats combining X-ray fluoroscopy, and three dimensional GRF during active perturbations were performed. They indicate that the shaker may play a key role in determining motor-control strategies in response to active perturbations during posture and locomotion in small animals.

**Keywords:** Active perturbations · Locomotion · Neuromechanics

## 1 Introduction

In the last years, spinal sensorimotor systems have been studied extensively. Canonical mammalian spinal circuits were organized in Ia, reciprocal inhibitory system, Renshaw cells, Ib, and group II neurons e.g., [1]. Other works have focused on the pattern generating networks responsible for locomotion e.g., [2]. Despite important advances in the understanding of the organization of spinal motor systems, many aspects of spinal sensorimotor function remain unclear. For example, less is known about the descending systems in the brainstem and how they interact with spinal circuits [3, 4]. In addition, how do these systems ensure stable motor performance across unexpected changes in the environment? Or how do descending systems from the brainstem interact with spinal sensorimotor systems to produce flexible motor function? Understanding those questions requires a multidisciplinary approach. In the Neuronex project (C3NS) [5], we combine behavioral, neurophysiological, computational, and robotic experiments to understand how mechanical scale and task demands determine the function of low-level control centers in the spinal cord and their interactions with high level control centers in the brainstem in small mammals.

To infer the neuromechanical control strategies implemented by any animal, it is necessary to characterize how it responds to external perturbations. In the literature,


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biomechanists used "passive" perturbations, e.g., sudden drops [6, 7] or steps [8] to mimick, as far as possible, animal locomotion on rough terrains. We think, however, that to infer the interactions between spinal-reflex control and higher locomotor centers, reproducible "active" perturbations are necessary. They can help to search, for example, for the existence of a perturbation threshold at which spinal-reflex loop need to be helped by higher centers. In such a case we expect a sudden change in the kinematics, kinetics, and muscle activations.

In this paper, we mainly inform about a novel platform for neuromechanical experiments that we termed 'the shaker'. We also present shortly ongoing preliminary locomotion experiments on rats. The paper closes with the introduction of more complex experiments that will be undertaken to determine control strategies in response to perturbations during posture/locomotion in small animals.

## 2 The Shaker: A Three Degrees of Freedom Active Perturbation Platform

The shaker was designed for neuromechanical behavioral experiments during posture and locomotion of small animals (e.g., small mammals like rats or small terrestrial birds like the quail). Our design goal was that the shaker generates single or combined horizontal, vertical, and tilting perturbations with a payload up to 1 kg. During terrestrial locomotion, small animals exhibit contact times ranging between 0.1 s and 0.2 s depending on locomotion's speed. Therefore, every active perturbation applied by the shaker needs to be achieved in a time below 0.1 s. To fulfill the requirements during striding locomotion, the shaker was conceived to generate horizontal and vertical perturbations with amplitudes up to 1 cm at oscillation frequencies up to 10 Hz (repeat accuracy $<$ 0.1 mm). Tilting perturbations are aimed only for posture experiments and therefore do not need to satisfy such higher oscillations rates. To permit the collection of single leg ground reaction forces (GRF) before, during and after the active perturbations, up to four force plates (like those presented in [9]) can be integrated into the platform. In our posture/locomotion experiments we use biplanar high-speed X-ray fluoroscopy to infer bones kinematics in three dimensions. Therefore, the active platform of the shaker was designed to be, as far as possible, X-ray transparent.

In Fig. 1A, the CAD design of the saker is shown. The support platform consists of two carbon plates with an elastomer in between (thickness = 6 mm) and two or three carbon tubes (external diameter $\phi = 25$ mm, wall thickness = 1mm). On the support platform, a ring made of Polyoxymethylene (POM) was rigged to permit the mounting of up to four ATI-Nano 17® force/torque sensors. Four plates made of acrylic glass (10 cm $\times$ 10 cm $\times$ 0.5 cm) were used as a platform for collecting GRFs and center of pressure (CoP) (see Fig. 1B).

The vertical oscillations of the platform (z-axis) are produced by two linear servomotors (Beckhoff, mod. AL8042). The horizontal ones (x-axis) by one linear servomotor (Beckhoff, mod. AL8040). Those linear motors are controlled by digital compact servo drives (Beckhoff, mod. AX5206, respectively Beckhoff, mod AX5106). Maximal translation amplitude ratio is 2 cm in 0.05 s. The tilting motions of the platform (about the y-axis) are produced by two stepper motors Nanotec (mod. LA421S14-B-UIEV) controlled by a Beckhoff motor controller (mod. EL7031–0030). Maximal angular displacement ratio is around 15°/ s. GUI and control programs were written in Beckhoff own software-environment (Beckhoff TwinCAT). Time dependent perturbation profiles can be freely designed using coma separated values (csv. File). Perturbation's release can be achieved manually or by means of a photoelectric sensor. The shaker was developed and constructed by H&S Robotics, Ilmenau, Germany.

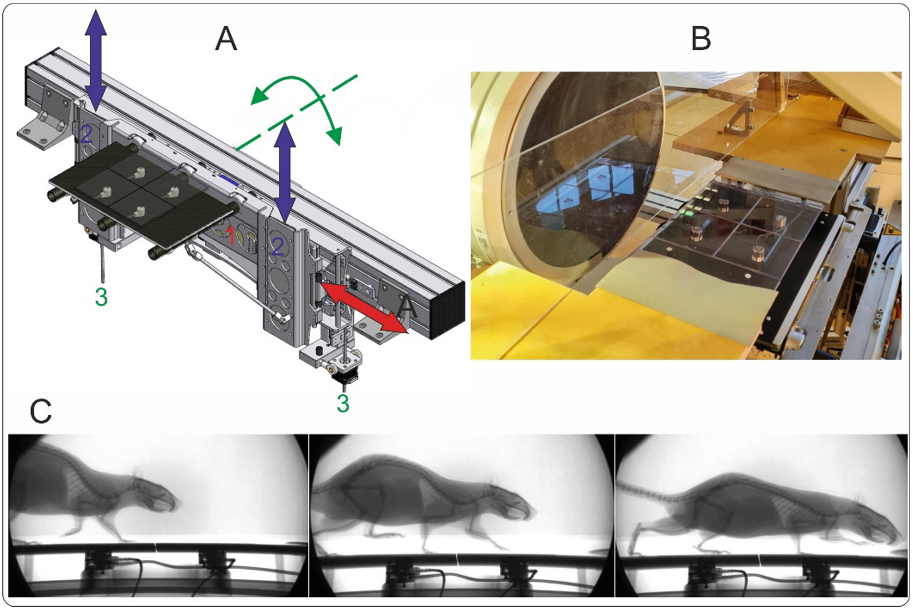


**Fig. 1.** The shaker and preliminary experiments. A) CAD image of the shaker indicating the motors and degrees of freedom: (1) one linear servomotor, horizontal motion along x-axis (red), (2) two linear servomotors, vertical motions along z-axis (blue), (3) stepper motors, tilting motions about y-axis (green). B) Platform with force plates and walking track. C) Pictures from X-ray video (600 f/s) showing a sudden drop of the platform of 10 mm in 0.05 s.

## 3 Preliminary and Coming Experiments

Two adult rats (*Rattus Norvegicus*) displaying a weight of 250 g and 340 g moved across a 2.3 m walking track, constructed around the shaker, at their preferred speeds. Body and limb kinematics were collected by using a biplanar high-speed X-ray fluoroscope (Neurostar, Siemens, Erlangen, Germany) and two synchronized standard light high-speed cameras (SpeedCam Visario g2, Weinberger, Erlangen, Germany). One plane of the X-ray machine recorded the motions of the rat on the sagittal plane (see Fig. 1B and C). The second plane, which normally records from above the animal, was rotated 30° form the vertical position to minimize interference with the force/torque sensors and to improve the recognition of the tantalum beans after motion‘s capture. The X-ray machine parameters were 55 kV and 40 mA, and a sampling frequency of 600 Hz. GRFs were collected at 1.2 kHz and force and X-ray data synchronized electronically (post-trigger). Onset of perturbation and force data were synchronized using a visual signal integrated in the shaker, which was captured by the light high-speed cameras. This synchronization is necessary to subtract the forces induced by accelerations (measured without payload) to those collected during posture/locomotion experiments.

In the preliminary phase of our experiments (Fig. 1C), we applied only one-way linear perturbations of 10 mm or 5 mm in 0.05 s during locomotion. Perturbations were termed cranial and caudal, ventral and dorsal (representing forward and backwards, downwards and upwards directions). Combination of those perturbations are expected to be used in the future. The Committee for Animal Research of the State of Thuringia, Germany, approved the animal care and all experimental procedures (registry number: 02-060/16). In coming experiments, we aim to combine three-dimensional bone kinematics with three-dimensional GRFs, and recordings of muscle activation during active perturbations. For this, rats will be implanted with tantalum beads (diameter: 0.5 mm) and EMG electrodes. We expect that by measuring motor responses to a range of perturbations, we can define the functional mapping between deviations in limb state, center of mass dynamics, and muscle activations.

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