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Automated touch sensing in the mouse tapered beam test using Raspberry Pi

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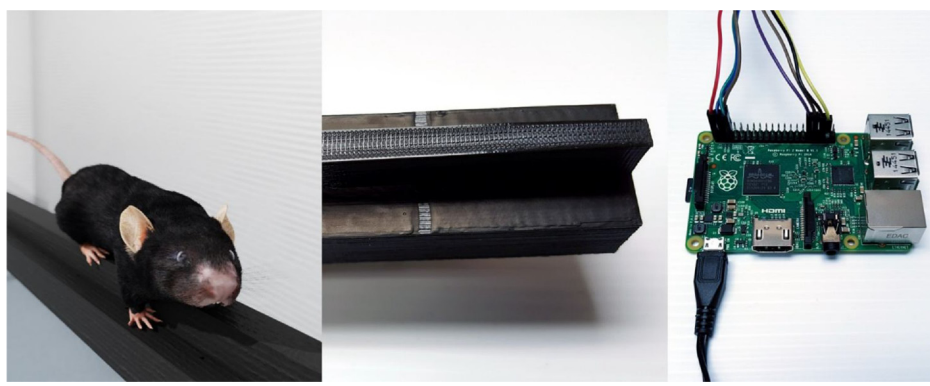
HIGHLIGHTS

- Easy-to-implement adaptation to existing tapered beam test in mice.
- Automation of foot fault detection saves time and increases objectivity.
- Inexpensive hardware and open-source software in Python.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Rodent models of neurological disease such as stroke are often characterized by motor deficits. One of the tests that are used to assess these motor deficits is the tapered beam test, which provides a sensitive measure of bilateral motor function based on foot faults (slips) made by a rodent traversing a gradually narrowing beam. However, manual frame-by-frame scoring of video recordings is necessary to obtain test results, which is time-consuming and prone to human rater bias.
New method: We present a cost-effective method for automated touch sensing in the tapered beam test. Capacitive touch sensors detect foot faults onto the beam through a layer of conductive paint, and results are processed and stored on a Raspberry Pi computer.
Results: Automated touch sensing using this method achieved high sensitivity (96.2%) as compared to 'gold standard' manual video scoring. Furthermore, it provided a reliable measure of lateralized motor deficits in mice with unilateral photothrombotic stroke: results indicated an increased number of contralesional foot faults for up to 6 days after ischemia.
Comparison with existing method: The automated adaptation of the tapered beam test produces results immediately after each trial, without the need for labor-intensive post-hoc video scoring. It also increases objectivity of the data as it requires less experimenter involvement during analysis.

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Conclusions: Automated touch sensing may provide a useful adaptation to the existing tapered beam test in mice, while the simplicity of the hardware lends itself to potential further adaptations to related behavioral tests.

1. Introduction

Motor deficits are a common phenotype in rodent models of neurological disease such as stroke or traumatic brain injury (Caleo, 2015; Yang et al., 2013). Tests of motor function can serve as important readouts of underlying neurological function and are often used to assess the severity of a neurological condition or the efficacy of a new treatment (Brooks and Dunnett, 2009). One of the tests frequently used in mice is the tapered beam test (Bye et al., 2007; Schallert et al., 2002). This test requires the animal to traverse an elevated beam that becomes gradually narrower towards the end (Fig. 1). Side ledges extend to the left and right side underneath the beam, such that a mouse that slips will put its foot onto the side ledge to retain balance. The number of foot faults (slips) made by the mouse provides an inndication of motor function and is asymmetrical in case of unilateral deficits (Schallert et al., 2002).

Although the tapered beam test can provide sensitive measurements of (lateralized) motor deficits, it requires laborious frame-by-frame scoring of video recordings and is therefore prone to systematic bias introduced by the human rater. Thus, automation of behavioral tests like the tapered beam test can help maximize objective measurement and reduce time spent on data processing.

We present an easy-to-use automated adaptation of the tapered beam test in mice. Using low-cost capacitive touch sensors connected to a Raspberry Pi single-board computer, foot faults onto the side ledge are detected in real-time and results are available immediately after each trial. The goal of this study was to assess the sensitivity of automated foot fault detection and to confirm the validity of the automated tapered beam test as a measure of lateralized motor deficits. We hypothesized that this test 1) achieves high sensitivity for foot fault detection as confirmed by 'gold standard' video analysis, and 2) provides a valid measure of lateralized motor deficits after unilateral stroke.

2. Methods and materials

2.1. Components and construction

All components necessary for automated foot fault detection in the tapered beam test are listed in Table 1. For a step-by-step construction tutorial see Supplementary video.

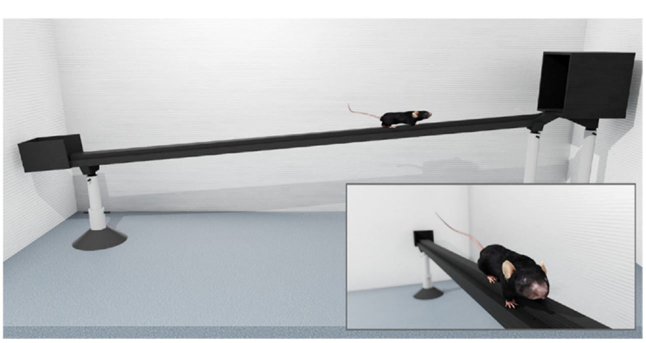

Fig. 1. Rendered image of the tapered beam. The apparatus includes a loading area at the left end and a refuge box at the right end of the beam. Inset: close-up view of a mouse stepping onto the side ledge (foot fault).

The tapered beam was constructed from five individually 3D-printed modules (Supplementary File 1) and followed the dimensions typically used in the mouse literature (e.g. Bye et al., 2007; Corrigan et al., 2012). Thus, the beam measured 100 cm in length, tapering from 3.5 cm to 0.5 cm from one end to the other, and featured a wider base part 1 cm below the upper surface of the beam to provide side ledges extending 1 cm to the left and right (Fig. 1 inset). Although the 3D-printable design was optimized for easy implementation of automated foot fault detection, any regular tapered beam could in principle be used as well.

Touches onto the side ledges were recorded through a layer of conductive paint (Bare Conductive, London, UK) which was divided into 23 non-interconnected surfaces per side measuring 4×1 cm each, together spanning around 92 cm of the beam's total length (Fig. 2A). These conductive paint surfaces served as input electrodes for four 12-channel capacitive touch sensors (Adafruit Industries, New York, NY, USA) which together provided 48 channels. The remaining two input electrodes were painted on the top surface at either end of the beam to record the start and finish times of each trial. As the water-based paint dissolves easily when cleaning the beam with soap and water or alcohol, we applied a layer of polyurethane finish to protect the electrodes. This procedure, despite insulating the paint, did not hinder the recording of touches since capacitive touch sensors do not require direct electrical contact. The electrodes were connected to the touch sensors by means of jumper wires, which were plugged into the beam to make contact with the conductive paint on one end, and connected to header pins on the touch sensor on the other end (Fig. 2B).

The capacitive touch sensors were connected to a Raspberry Pi single-board computer (Fig. 2C) to process and store the data using custom software written in Python (van Rossum, 1995). These scripts are provided in Supplementary File 2. Readout parameters include the total number of foot faults, number of foot faults per side, time to traverse the beam, time to first foot fault, and (approximate) distance to first foot fault. More information such as the exact

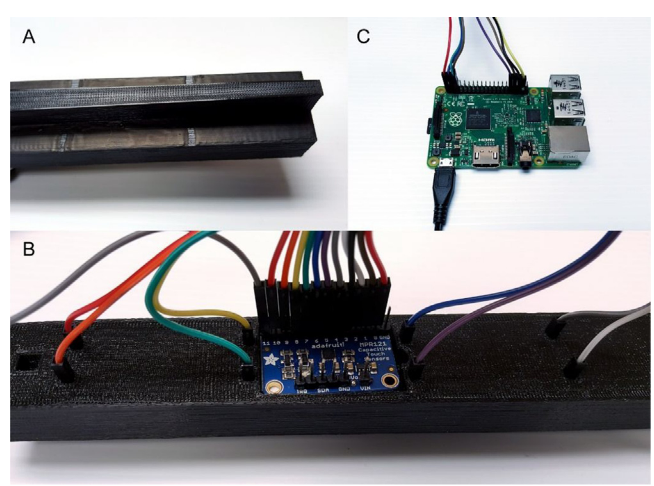

Fig. 2. Assembly of the automated tapered beam apparatus. A) Electrode surfaces are painted onto the side ledges to the left and right of the beam (top view). B) Jumper wires connect the electrodes to the capacitance sensor chips (bottom view). C) Logic and power connections are fed into the Raspberry Pi computer.