Journal of Neuroscience Methods 264 (2016) 57–64

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

An automatic experimental apparatus to study arm reaching in New World monkeys

Allen Yin[a,b,1], Jehi An[a,b,1], Gary Lehew[b,1], Mikhail A. Lebedev[a,b], Miguel A.L. Nicolelis[a,b,c,d,e,*]

[a] Department of Biomedical Engineering, Duke University, Durham, NC, USA
[b] Duke Center for Neuroengineering, Duke University, Durham, NC, USA
[c] Department of Neurobiology, Duke University Medical Center, Durham, NC, USA
[d] Edmond and Lily Safra International Institute of Neuroscience of Natal, Natal, Brazil
[e] Department of Psychology and Neuroscience, Duke University, Durham, NC, USA

HIGHLIGHTS

- An automated apparatus is developed for controlled experiments for small primates.
- Owl monkeys learned a visually-cued task using the apparatus.
- Neural recordings show direction tuning of M1 neurons.

ARTICLE INFO

Article history:
Received 17 December 2015
Received in revised form 18 February 2016
Accepted 22 February 2016
Available online 27 February 2016

Keywords:
New World monkeys
Animal model
Behavior
Neural recordings
Arm reaching
Experimental control

ABSTRACT

Background: Several species of the New World monkeys have been used as experimental models in biomedical and neurophysiological research. However, a method for controlled arm reaching tasks has not been developed for these species.
New method: We have developed a fully automated, pneumatically driven, portable, and reconfigurable experimental apparatus for arm-reaching tasks suitable for these small primates.
Results: We have utilized the apparatus to train two owl monkeys in a visually-cued arm-reaching task. Analysis of neural recordings demonstrates directional tuning of the M1 neurons.
Comparison with existing method(s): Our apparatus allows automated control, freeing the experimenter from manual experiments.
Conclusion: The presented apparatus provides a valuable tool for conducting neurophysiological research on New World monkeys.

1. Introduction

New World monkeys include a diverse group of five families of primates of Parvorder *Platyrrhini*, primarily living in the tropical forests of South America. These primates are small to mid-sized ranging from the pygmy marmoset, at 14 to 16 cm and a weight of 120 to 190 g to the southern muriqui, at 55 to 70 cm and a weight of 12 to 15 kg. Several species of Platyrrhini have been studied in biomedical research including squirrel monkeys (Abee, 1989; Nudo and Milliken, 1996; Nudo et al., 1996), the common marmoset (Mansfield, 2003; Takemoto et al., 2011), and owl monkeys (Allman and Kaas, 1971; Merzenich et al., 1983; Kaas, 1987; Nicolelis et al., 1998; Wessberg et al., 2000; Bao et al., 2004). The nocturnal owl monkey (*Aotus trivirgatus*) has been of particular interest to neurophysiological study. It has a relatively smooth cortex which facilitates mapping (Allman and Kaas, 1971; Kaas, 1987) and allows implantation of a large number of microwires in multiple cortical areas (Nicolelis et al., 1998). Further, chronic cortical implants of microwire arrays in owl monkeys have been shown to maintain good neuronal recording quality for at least 3–5 years (Sandler, 2005).

Arm reaching tasks have been of particular interest in neurophysiological research, used often to study neural encoding of movement (Georgopoulos et al., 1986, 1988; Kettner et al., 1988; Schwartz et al., 1988; McIntyre et al., 1998; Lebedev and Wise, 2001), visuo-motor systems (Flash and Henis, 1991; Wise et al.,

* Corresponding author at: Duke University, Dept. of Neurobiology, Box 3209, Durham, NC 27710, USA. Tel.: +1 919 684 4580; fax: +1 919 668 0734.
E-mail address: nicoleli@neuro.duke.edu (M.A.L. Nicolelis).
[1] The three authors contributed equally for this study.

http://dx.doi.org/10.1016/j.jneumeth.2016.02.017
0165-0270/

1992; Lacquaniti and Caminiti, 1998; Batista et al., 1999), and most recently brain-machine interfaces (BMIs) (Wessberg et al., 2000; Carmena et al., 2003; Scherberger et al., 2003; Lebedev and Nicolelis, 2006; Scherberger and Andersen, 2007; O'Doherty et al., 2011; Ifft et al., 2013). Most of these studies, with a few exceptions (Wessberg et al., 2000; Fitzsimmons et al., 2007), have been performed on *rhesus* monkeys, resulting in a host of experimental apparatuses targeted toward this species (Livesey et al., 1972; Mitz et al., 2001; Mitz, 2005; Wilson et al., 2005). Yet, a thorough method for executing arm reaching experiments with New World monkeys has not been sufficiently developed.

Since New World monkeys present an attractive experimental model for neurophysiological recording in behaving primates, we sought to build an experimental apparatus for arm-reaching tasks suitable for this small primate species. Such an apparatus needs to be fully automated, include natural reinforcement methods for training the monkey, convenient ways to manipulate attention and detect monkey movements, and produce low electrical noise in neural recording experiments. The fully automated, portable apparatus presented here addressed these requirements by integrating a customizable pellet feeder, visual stimuli, and pneumatically controlled actuators. This device operated successfully in training owl monkeys to perform visually-cued reach tasks and later in intracortically stimulated reach tasks and may be applied to a variety of neurophysiological and BMI studies.

2. Materials and methods

2.1. Operation overview

The device (Fig. 1) consists of three doors, three pellet dispensers, and three traps assembled onto a metal barrier, which is mounted on a linear slider, totaling 10 degrees of freedom. Each degree of freedom is driven by a pneumatic cylinder (20–40 psi) to eliminate electrical noise in neural recording. In an experiment, pellets are dispensed into the traps and then cleared away. If the metal barrier is at a forward position on the slider close to the monkey, and the door corresponding to that trap is open, then the monkey can obtain the reward.

2.2. Pneumatics

A manifold of eight 4-way two-position solenoid air valves (Numatics 226-432B) is used to control the air cylinders. The trap cylinders are controlled by a single air valve, whereas every other cylinder has a valve dedicated to it alone. A 24 V DC-power supply powers the manifold, and a single source of compressed air is connected to the input of manifold.

An array of 8 optoisolators (IXYS LCA710) mounted on a custom printed circuit board (PCB) is used to electronically control the valves. An optoisolator acts as a switch opening or closing the connection between the 24 V power supply and a valve, depending on its input signal. Closing the connection activates the corresponding valve, changing the direction of air flow through it. The optoisolators take 5 V signals as inputs, allowing them to easily interface to the GPIO pins of many micro-controllers (Arduino, Trinket 5 V, Pinguino, Raspberry Pi, etc) as well as the National Instrument Data Acquisition (NIDAQ) system. Indicator LEDs at the input pins of the optoisolators light up when the corresponding valve is activated.

The pneumatic air cylinders are double-acting: they have air pressure ports on each end of the cylinder which force a plunger to either extend or retract by applying pressure to one port while venting the other in a controlled manner. The speed of application and venting of the pressure establishes the speed of the plunger movement. A rod is attached to the plunger that serves to transmit the motion to the mechanism it drives.

2.3. Base slider

The linear slider consists of a rectangular aluminum plate (50 cm × 11 cm) mounted on a slider carriage riding on a modified box rail. The box rail itself is mounted onto the back side of a half-square tube (see Fig. 2A). The double-acting cylinder is bolted onto the bottom side of the half-square tube with its rod attached to the back of the aluminum plate via an angle bracket.

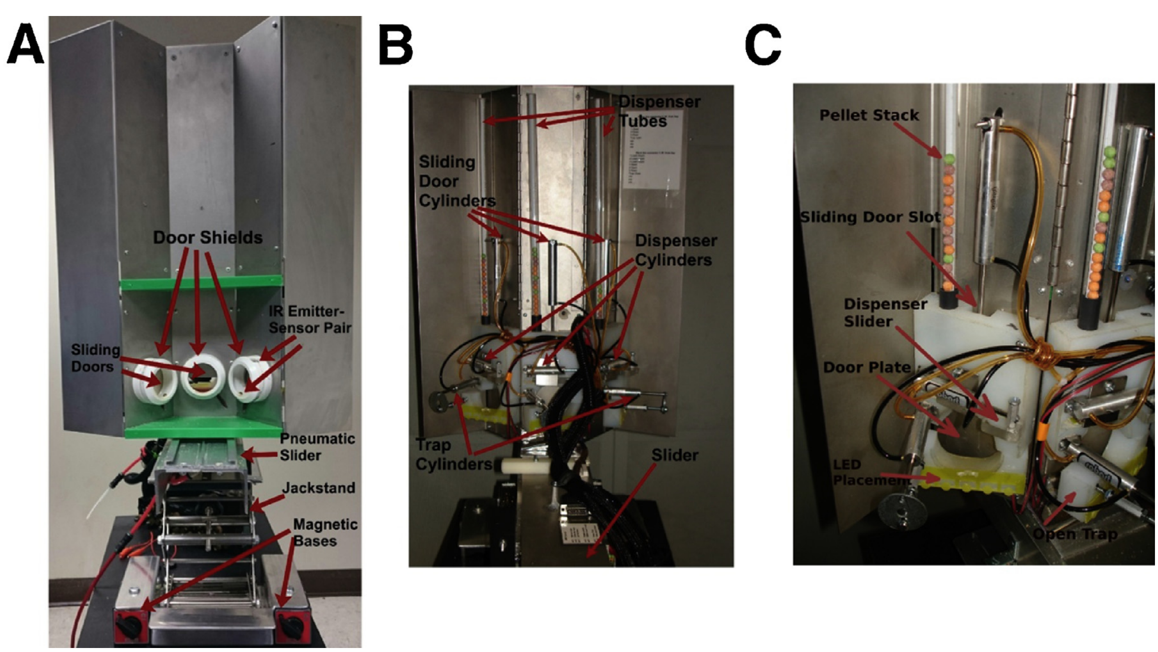

Fig. 1. Experimental apparatus. (A) Front view of the experimental apparatus with the jack stand raised. In the figure, the middle sliding door is half lowered. (B) Back of the apparatus. (C) A detailed view of the pellet dispenser and the door assembly. Both traps in the picture are open while the sliding doors are closed. The LED is not shown but its placement is labeled.