Low-cost, portable, easy-to-use kiosks to facilitate home-cage testing of non-human primates during vision-based behavioral tasks

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Non-human primates, especially rhesus macaques, have played a significant role in our current understanding of the neural computations underlying human vision. Apart from the established homologies in the visual brain areas between these two species, and our extended abilities to probe detailed neural mechanisms in monkeys at multiple scales, one major factor that makes NHPs an extremely appealing animal model of human-vision is their ability to perform human-like visual behavior. Traditionally such behavioral studies have been conducted in the controlled laboratory settings. Such in-lab studies offer the experimenter a tight control over many experimental variables. However, typical constraints related to such experiments include, 1) limited total experimental time, 2) requirement of dedicated human experimenters for the NHPs, 3) requirement of additional lab-space, 4) additional time and training required for chairing and head restraints of monkeys, 5) NHPs often need to undergo invasive surgeries for a head-post implant. To overcome these limitations, many laboratories have now adapted home-cage behavioral training and testing of NHPs. Home-cage behavioral testing enables the administering of many vision-based behavioral tasks simultaneously across multiple monkeys with much reduced human personnel requirements, no NHP head restraint, and provide NHPs access to the experiments without specific time constraints. Here, we provide the details of operating and building a portable, easy-to-use kiosk for conducting home-cage vision-based behavioral tasks in NHPs.

Non-human primates | kiosk | home-cage | visual psychophysics

SUMMARY

This article will summarize the operation and building blocks of a low-cost, portable, easy-to-use kiosk developed in our laboratory at York University (Toronto, Canada). The design and motivation for the kiosk have been heavily inspired by earlier work from Elias Issa in the laboratory of James J DiCarlo at the McGovern Institute of Brain Research at MIT (Rajalingham et al., 2018; Kar et al., 2019). The primary goal of this article is to make the details of our version of the kiosks readily available across the NHP laboratories worldwide. An elaborate pictorial depiction of the kiosk (as provided here) will also allow laboratories (that have mechanical workshops

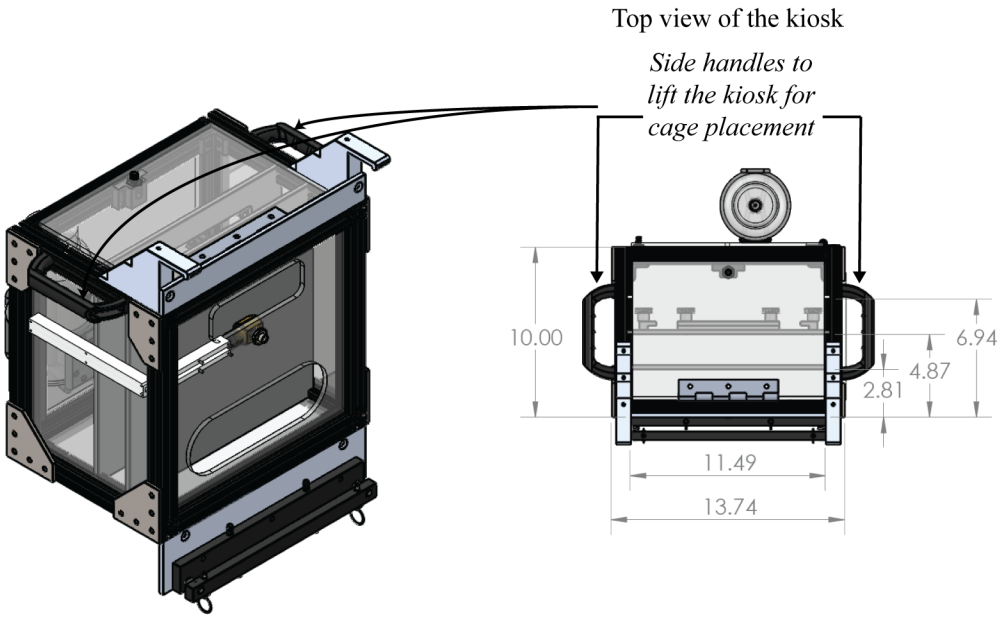

Fig. 1. Lifting the kiosk. Primarily, the kiosk is lifted by the experimenter immediately before placing it on the cage. There are two handles of the side that allow the experimenter to lift the ∼25-30 lbs kiosk.

available to them via their university or departmental resources) to get a gist of the mechanisms involved and quickly produce a customized version for use. Adopting these kiosks will enhance NHP research, and openly sharing our design will help us improve them in the future. We also expect to update this article as we continue incorporating additional capabilities into this system.

Interaction of the human experimenter with the kiosk

The kiosk is approximately 25-30 lbs. in weight. The National Institute for Occupational Safety and Health (NIOSH) has created a mathematical model that can predict the chance of injury when lifting weights, taking into consideration factors such as weight, frequency of lifting, and movement during lifting. A lifting equation (see http://www.cdc.gov/niosh/docs/94-110/), calculates a recommended weight limit for one individual in various situations. The lifting equation establishes a maximum load of 51 pounds, which is then adjusted based on various factors, including how often the weight is lifted, the twisting of the back during lifting, the vertical distance the load is lifted, the distance of the load from the body, the distance moved while lifting the load, and the ease of holding onto the load. Given that the kiosk can be carried around in a cart, and only needs to be lifted right before placing it on the cage bars, the overall time of lifting as well as its total weight fits the capacity of most experimenters and are within the NIOSH estimated limits. **The experimenter should lift the kiosk by its side using the protruding handles** (**Figure 1**). In an alternate model of the kiosk, the handles can be also placed vertically (instead of horizontally).

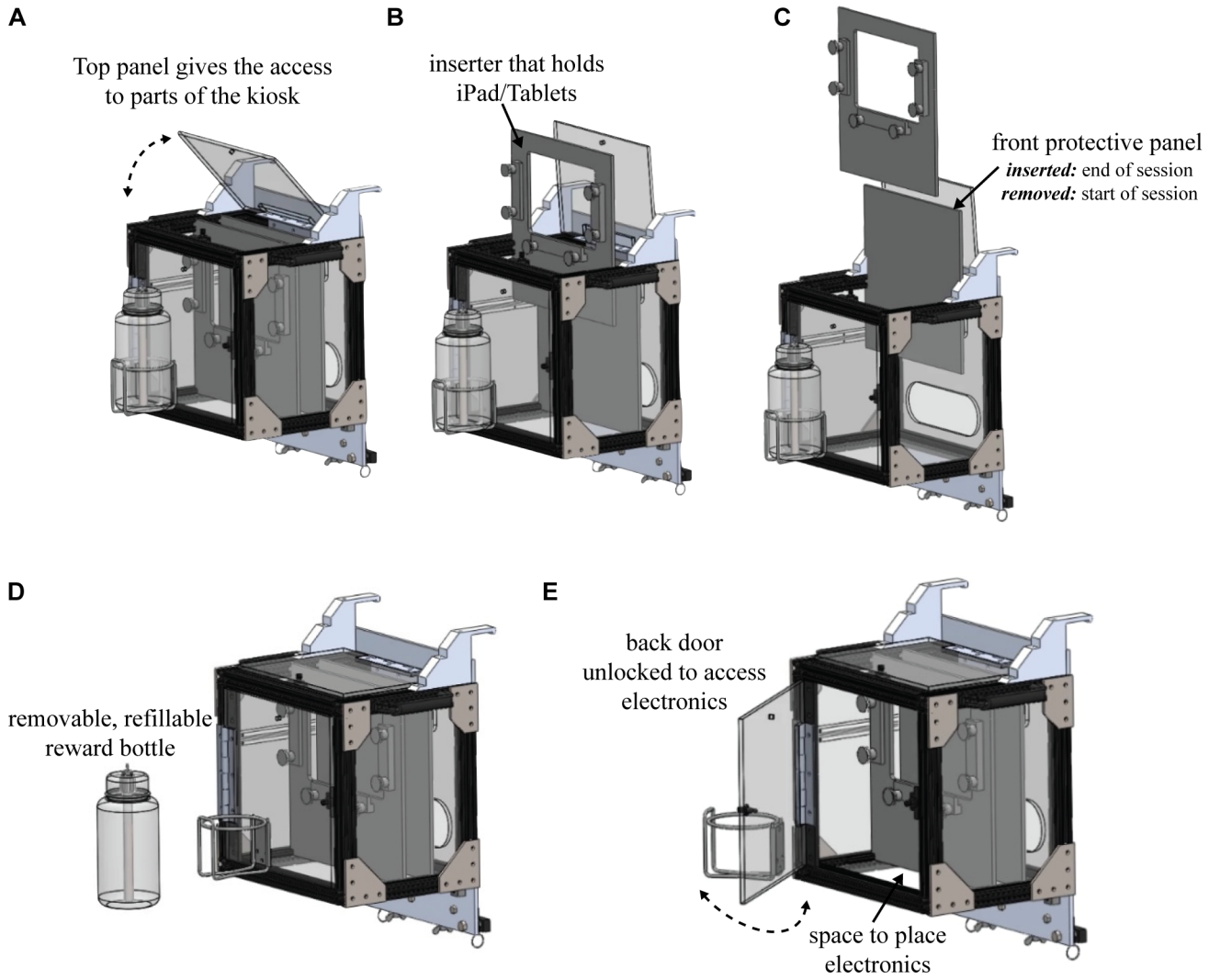

Fig. 2. Interacting with the kiosk. **A.** The top panel that remains attached to the kiosk can be opened to access the rest of the kiosk. **B.** One of the detachable inserter panels holds the tablet/touch screen. **C.** A protective front panel is inserted at the end of the experimental session to protect the electronics at the back of the kiosk from the monkey. It is also removed at the beginning of the session to allow the monkey full access to the touch screen. **D.** A removable bottle is placed in a dedicated attachment in the back of the kiosk to hold the reward fluid (typically water).The bottle can be removed daily to refill the fluid. **E.** The back door (that stays attached to the kiosk) can be opened to insert the electronics, and make proper adjustments (e.g., tighten the tablet into the inserter).

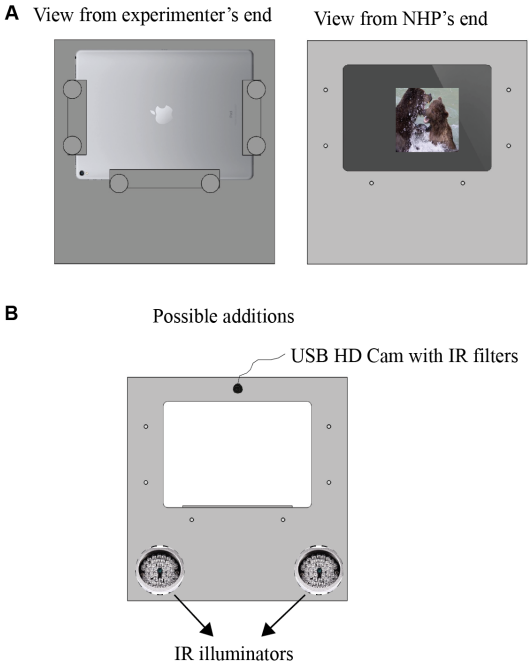

Fig. 3. The touch screen/tablet inserter panel. A. *Left Panel:* The view from the experimenter's end. The knobs can be loosened to insert the tablet from the top of the kiosk. The back of an iPad is visible in the figure as an example configuration. *Right Panel:* The view from the monkey's end. The visual stimulus can be seen in the example. The monkeys can touch this screen to indicate their choices. **B.** Possible items to add to the setup via this inserter. Apertures can be drilled at the bottom to allow for two IR illuminators. A small hole at the top of the inserter panel can be used to insert a high-definition USB camera with an IR filter. These can be combined to develop a low-cost eye tracking system (available in future versions of the kiosk).

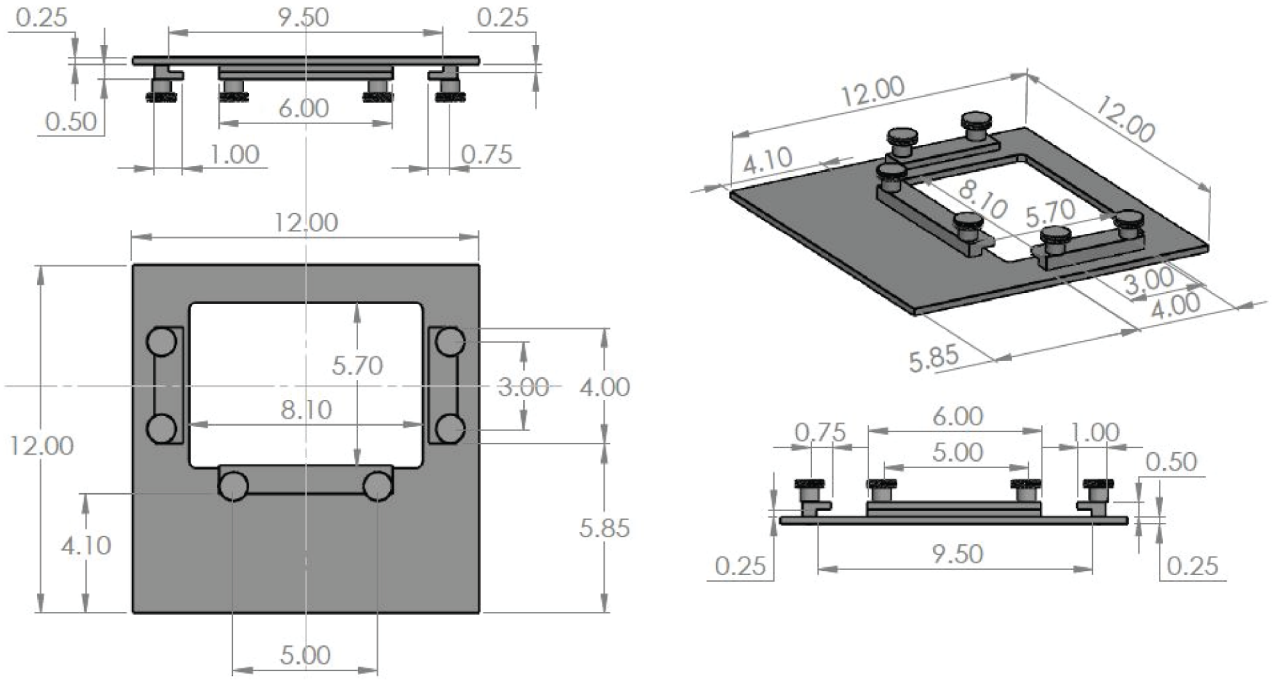

Fig. 4. The dimensions of the touch screen/tablet inserter panel. The exact dimensions can vary based on the make of the tablet used. The aperture size can be smaller than the touch screen if the entire screen is not utilized in the tasks. However, the size shouldn't be larger than the touch screen since that will allow the monkeys to access the electronics (usually placed behind the touch screen).

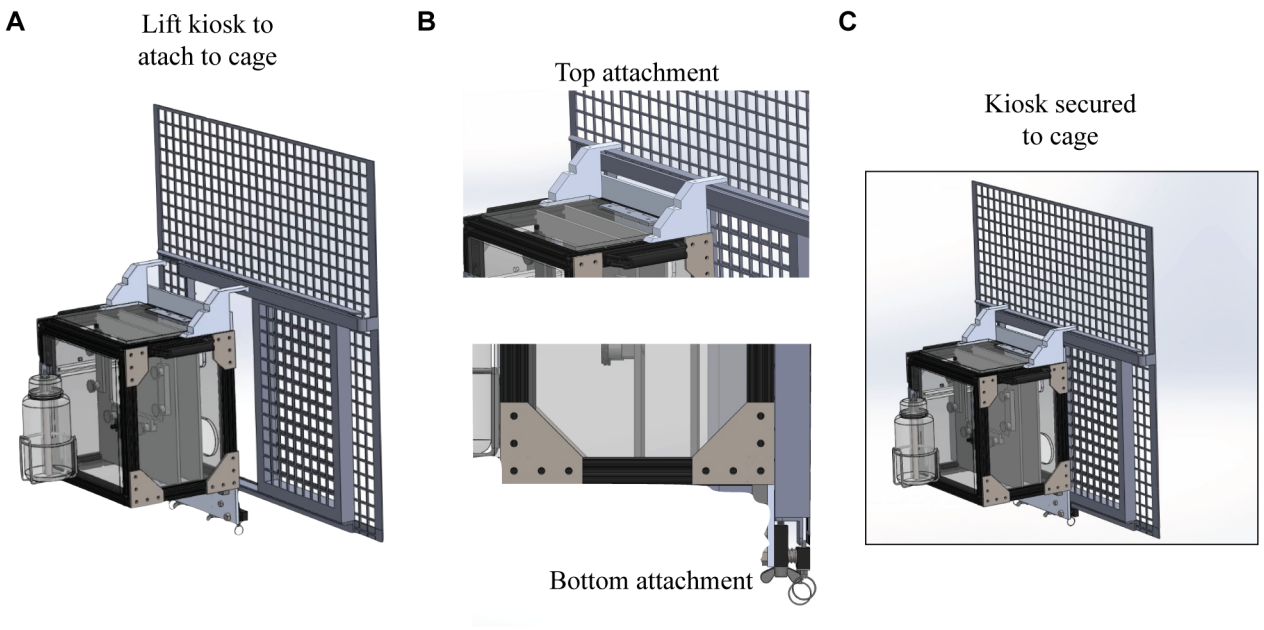

Fig. 5. Securely attaching the kiosk to the cage. A. The kiosk can be attached to the cage **B.** The top part of the kiosk slides into the cage, while the bottom has a locking mechanism that holds it in place such that the NHP cannot move the kiosk. **C.** Once placed correctly has no exposed gaps that can encourage the NHP to shake the kiosk. To get a closer look at how the kiosk should be placed, kindly refer to the following video, https://github.com/vital-kolab/nhp-turk/blob/main/videos/Placement.mp4

Attaching the kiosk to the cage

The kiosk needs to be securely attached to the top (**Figure 5B**: top panel) and the bottom (**Figure 5B**: bottom) of the cage opening with specific mechanisms (see our demo videos on GitHub Placement.mp4 for details and part list). Please refer to the supplemental video to observe the exact locking mechanisms that prevent the kiosk from being detached from the cage (regardless of any force applied by the NHP). Given that NHP cages come in various configurations, the exact attachment styles will likely need to be modified to cater to individual caging systems.

The internal components of the kiosk

When the monkey has access to the kiosk (that is when the kiosk is securely attached to the cage), experimenters can still access parts of the kiosk to make necessary changes to the experiments, change out the reward fluid, replace batteries for the tablet (or other electronics, e.g., Arduinos, Raspberry Pi). **Majority of the components like the side walls of the kiosk, the inserter panels, and the top and the back panel doors are all polycarbonate sheets.** All parts have been itemized (see e.g. in **Figure 6**) and shared at Bill of materials.xlsx. The following are the most relevant components of the kiosks with respect to the experimenter's needs:

The top panel (non-detachable from the kiosk). The top panel door can be pulled open to access the content of the kiosk (**Fig. 2A**). Typically, one would open it in the beginning of the experimental session to insert the tablet/touch screen into the kiosk. The experimenter can also place dry treats and toys into the front end of the kiosk during initial days of the NHP training to make the NHP feel motivated to insert their hands into the kiosk. They can also adjust the electronics at the back of the kiosk.

The two inserter panels (removable from the kiosk). The kiosk uses two panels that can be inserted into it. The front panel (**Fig. 2C**) is for protective purposes, and it is only inserted at the end of the experimental session, so that the monkey cannot access the electronics at the back of the kiosk.

Example contents of the Bill of materials

Part No. 1

Part Name	*Polycarbonate Sheet (Opaque)*
Description	*Inside dividers and Tablet inserters*
Vendor	*McMaster - Carr*
Vendor Part No.	*8574K211*
Quantity	*8*
Size per unit	*12" x 12" x 1/4"*
Unit cost (USD)	*16.94*
Total cost (USD)	*135.52*
URL	*https://www.mcmaster.com/8574K211/*

Fig. 6. Example contents of the Bill of materials. Please find an excel sheet with detailed information on all of these items for each part at https://github.com/vital-kolab/nhp-turk/blob/main/Bill.of.Materials.xlsx

Typically the tablet is removed for charging at the end of the day. Therefore the front panel has to be placed. This panel is also

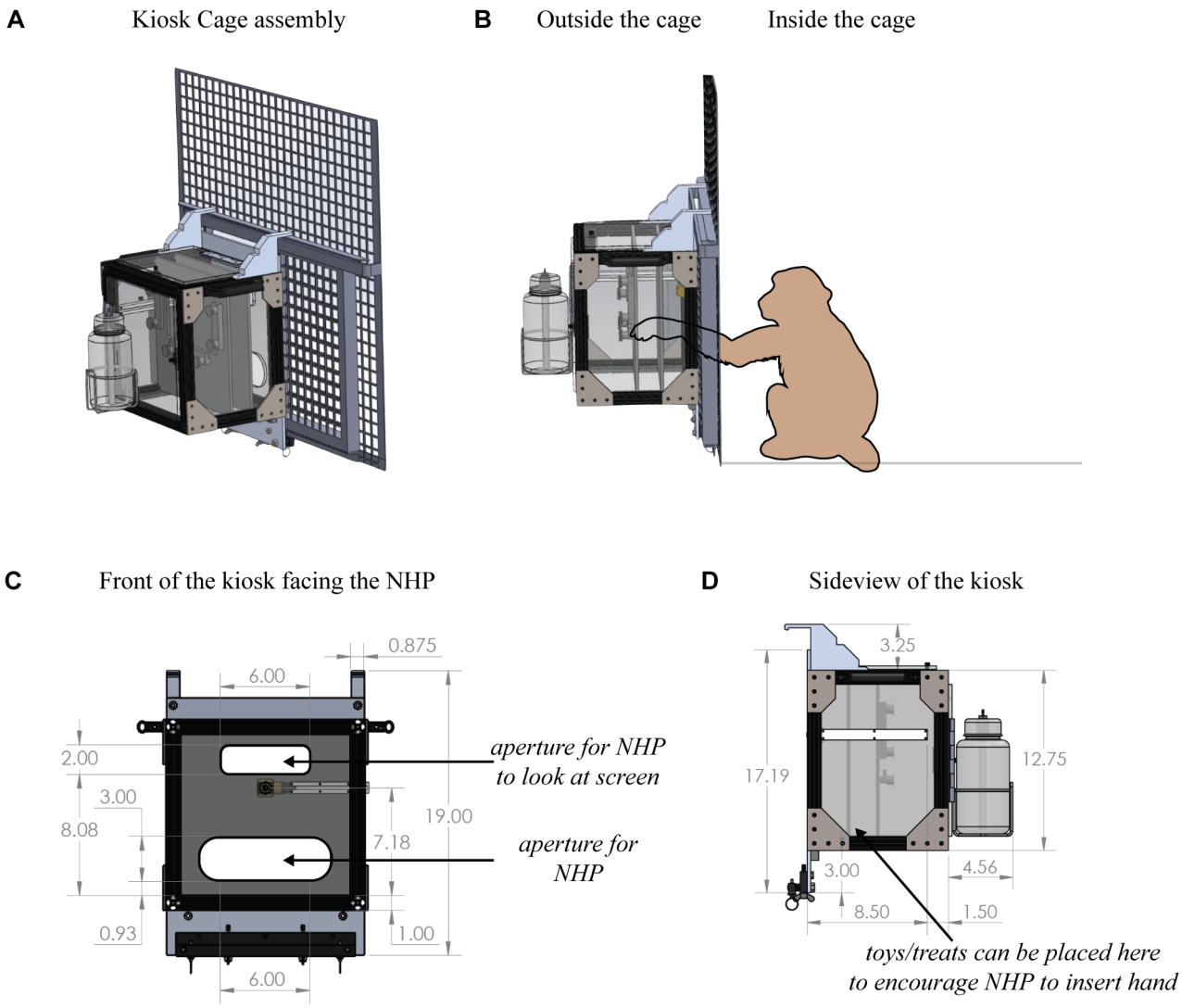

Fig. 7. Kiosk components critical for NHP interactions. A. Kiosk Cage assembly. Before the NHP is allowed to interact with the tablet by removing the front-most protective inserter panel, the kiosk has to be securely attached to the cage **B.** The monkey accesses the touch screen by sitting right infront of the kiosk on a horizontal cage divider panel. **C.** The front of the kiosk facing the NHP has two apertures. The top one allows for clear visual access to the NHP. The bottom one allows the NHP to insert its hand and interact with the touch screen. **D.** Sideview of the kiosk illustrates the space at the front that can be used to insert toys and treats to initially encourage the NHP to get their hands in via the aperture.

removed at the beginning of the experimental session so that the NHP can access the touch screen. The second inserter panel (**Fig. 2B**) holds the tablet/touch screen. This panel, ideally could be left in the kiosk at all times. The back of this panel (that is accessible to the experimenter when the NHP has access to the kiosks), has brackets and knobs to securely place an iPad or other tablets into that slot (see **Figure 3A**; *left panel*). The front of this panel has an aperture sized according to the dimension of the touch screen (**Figure 3A**; *right panel*). Depending on whether the vision tasks are conducted on iPads or Android tablets or via other means, the size of the aperture should be adjusted. The current dimensions of this inserter panel is provided in **Figure 4**. Other features to the kiosks, like eye tracking can be added by making modifications to this inserter panel (**Figure 3B**). For instance, an example strategy could involve making three additional holes on this inserter panel. Two of these could be at the bottom to accommodate two IR illuminators and one could be at the top to allow for a HD USB-based camera with IR filters. A combination of these can be used to set up a low cost eye tracker (*more details of this tracker will be published soon*).

The back panel (non-detachable from the kiosk). The back panel allows the experimenter to insert the electronics (**Fig. 2E**) associated with running the experiments. It is also attached to the section that contains the reward fluid bottle (**Fig. 2D**). The bottle has a tube inserted in it that is usually connected to a pump and then via another tube to a front nozzle (that the NHP uses to get the reward).

Interaction of the animal with the kiosk

To begin the experimental session, the kiosk must be first securely attached to the cage (**Figure 7A**). The kiosk can be placed both at the top-half or the bottom half of a standard NHP caging system. If it is placed in the top-half, a horizontal divider should be in place

to allow the monkey to rest on (**Figure 7B**) while they perform the behavioral tasks.

The animals have access (**Figure 7B**) to a touch screen (e.g., android tablets, Apple iPads) via two apertures (**Figure 7C**) in the front of the kiosk. The top aperture (see **Figure 7C** for dimensions) provides a clear, non-occluded visual access to the screen. It currently has a width of 6 inches which is broad enough to fit the monkeys where the maximum distance between the edges of the two eyes are usually $\sim$ 3 inches. The bottom aperture allows the monkey to reach inside with their hands and use the touch screen. Of note, it is important to make sure that the edges of this aperture has been additionally smoothened by the use of sand paper (or something similar), since rubbing along those edges (if not polished) might lead to minor cuts in the NHP arms. It is usually advised that the experimenter tests the kiosk in a lab setting with themselves (as subjects) first to ensure that everything is working correctly. In the beginning of the NHP training pipeline, the space between the touchscreen and the front screen may be utilized to place toys and treats (**Figure 7D**) so that the monkey feels motivated (and not afraid) to insert their hands through the aperture.

Concluding Remarks

The kiosk presented here should be considered as a work in progress. As we develop the system further, this article will be updated with that information. We encourage the NHP neuroscience research community to contact us with suggestions or clarification questions. This will help us improve the system and make it more versatile. Our next goals are to add a low cost eye tracking system (as mentioned in **Figure 3B**), and to release the code-base and material for the electronics that we are using. Our kiosks are fully compatible with behavioral testing of macaques paired with chemogenetic perturbations (currently used in this study: Kar et al., 2021), and wireless electrophysiological recordings. As we further develop those studies and techniques at York University, we shall update the system details through this article (or other similar documents).

Open-source material

The details of the kiosk can be found at the following GitHub page: https://github.com/vital-kolab/nhp-turk

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