TouchScope: A passive-haptic reading device to investigate tactile perception

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Word Count: 4110 words

Short title: TouchScope

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Author Note

This research was partially funded by Grants RED2018-102615-T, PSI2017-86210-P, and PGC2018-097145-B-I00 from the Spanish Government, and H2019/HUM-5705 from the Comunidad de Madrid.

Abstract

The sense of touch is underrepresented in cognitive psychology research. One of the reasons is that controlling the timing of stimulus presentation, which is a hallmark of cognitive research, is significantly more difficult for tactile stimuli than visual or auditory stimuli. To contribute to the development of tactile research, we present a system to display tactile stimuli and collect response time with the capability for static and dynamic (passive haptic) stimuli presentation. While the system requires some construction, it can be put together with commercially available materials. We present here the hardware and software implementation and some examples of experiments.

Keywords: Tactile perception, haptic perception, apparatus, braille

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Every student in an Introduction to Psychology class has seen the cortical homunculus with the oversized lips and fingers first described almost a century ago by Penfield and Boldrey (1937; see Figures 25-28). While the real estate of the tactile cortex is modest compared to the sprawling visual cortex, it is still sizable and important. Unfortunately for tactile research, the sense of vision has virtually monopolized the literature. A search of articles published in the journal *Behavior Research Methods* shows that out of 6,474 articles in the history of the journal until January 2021, 2755 include the word “visual”; this figure is 879 for the papers including the word “auditory”, and it is considerably lower for the articles including the words “tactile” (135) or “haptic” (53). While these counts are a coarse measurement of research activities, they reflect that tactile and haptic perception are understudied. Note that, in perception research, the term *tactile* is generally used to describe the sensations resulting from cutaneous stimulation, whereas the term *haptic* is used to describe those sensations that involve cutaneous stimulation and kinesthetics (see McGlone & Reilly, 2010; Wolfe et al., 2014).

One of the reasons (among many) for this state in the field is that presenting stimuli to the sense of touch—while accurately controlling their presentation—is significantly more difficult than presenting and controlling visual and auditory stimuli. In the visual modality, at the cost of an inexpensive computer, scientists have access to many platforms to carry out two critical tasks for research: selecting which stimulus is presented and controlling for how long it is presented (e.g., DMDX: Forster & Forster, 2003; PsychoPy: Peirce et al., 2019, to cite two examples). This has allowed scholars to design a number of paradigms and techniques that carefully control the presentation of visual stimuli. For instance, reading researchers have developed methods such as masked priming (Forster & Davis, 1984), rapid serial visual presentation (Forster, 1970), moving

window (McConkie & Rayner, 1975), or the gaze-contingent boundary change technique (Rayner 1975). Such control has allowed researchers to collect high-quality data – avoiding as much noise as possible – adequate for replicating many effects and developing sophisticated computational models of word recognition and text reading. Similarly, in auditory perception, even older technologies allow for some control over the timing of aural stimuli, like the classic dichotic listening tasks (Broadbent, 1958; Cherry, 1953), or more contemporary techniques like the so-called “subliminal” speech priming (Kouider & Dupoux, 2005).

Unfortunately, no equivalent devices or methods for the optimal control of the timing of presentation for tactile stimuli currently exist. In the present article, we aim to contribute to making tactile display and response collection more straightforward by providing researchers a system to select and present a tactile stimulus among a set of stimuli, with some control over the timing of such presentation. To that end, we use a refreshable braille display placed on a moving (or static) platform. This technology can explore many tactile perception phenomena, but its natural application is to study braille reading.

The Braille Writing System

The braille writing system was invented around 200 years ago by Louis Braille. In braille, different patterns of raised dots in a 2×3 matrix, called a *braille cell*, represent the written symbols of language such as letters (e.g., a = $\begin{smallmatrix} \bullet & \cdot \\ \cdot & \cdot \end{smallmatrix}$) or punctuation marks (e.g., ? = $\begin{smallmatrix} \bullet & \cdot \\ \bullet & \bullet \end{smallmatrix}$). One of the most common ways to access braille written information nowadays is via refreshable braille displays, which are electromechanical devices that allow braille readers to interact with computers, smartphones, and other gadgets (Perkins School for the Blind, International Council on English Braille & Library of Congress, 2013). Braille displays use 8-dot braille cells (i.e., 2×4

matrices; e.g., $a = \begin{smallmatrix} \bullet & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \end{smallmatrix}$), in which the bottom row is used, among other things, to make computer interaction easier (e.g., by showing the position of the cursor) or to represent some text

characteristics that otherwise will need the use of another cell, such as capitalization (e.g., $A = \begin{smallmatrix} \bullet & \cdot \\ \cdot & \cdot \\ \bullet & \cdot \end{smallmatrix}$; rather than $A = \begin{smallmatrix} \cdot & \cdot & \cdot \\ \bullet & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{smallmatrix}$ in 6-dot braille cells). The braille writing system offers a great set of stimuli to researchers interested in the sense of touch, those involved in reading research, and those interested in tactile and haptic perception in general (see Baciero et al., in press).

Requirements for a tactile stimulus presentation tool

Any device to study tactile and haptic processes requires several features to accurately display and control the stimuli, similar to what researchers in the visual and auditory modalities have; this research aims to fulfill the following five requirements:

1. *Stimulus control*. The system has to allow researchers to control stimulus onset, speed of presentation (when involving movement), and trial duration.
2. *Trial customization*. The tool should allow researchers to modify those parameters across trials.
3. *Modality appropriateness*. The tool should allow the display of the stimuli through the rubbing of the skin or even through some coarse location of the skin—note that these are crucial elements of haptic perception and braille reading.
4. *Automaticity*. The tool needs to present the stimuli in an automated manner (i.e., as in the experiments in the visual modality).

5. *Reproducibility and portability.* Everybody should be able to build it and move it where needed at reasonable costs.

Advances in technology during approximately the last decade have allowed the creation of fully automated devices that researchers can use to investigate tactile perception in different areas, such as braille reading and texture perception, although they still have some limitations.

For instance, researchers on braille reading have designed tools that can automatically track finger movements, thus allowing precise hand movement analyses during braille reading. Breidegard et al. (2008) created an *automatic finger tracking system* that simultaneously videotapes finger movements from above and below the hand. This system tracks the location of the fingers and analyzes their moving patterns automatically. Hughes (2011) developed a tool to measure the finger's movements while reading braille using a digitalizing tablet and attaching a digitalizing pen to the participant's index fingertip. Likewise, Aranyanack and Reilly (2012) devised a finger high-resolution tracking system using a Wii-remote control that can be used with both paper and refreshable braille displays and controls in a precise manner finger position within the word/text. Lei et al. (2019) also designed a tool to track finger position while reading by attaching electromagnetic sensors to the fingernails' top. Additionally, some refreshable braille displays (e.g., Active Braille; Help Tech., 2018) can track the finger's position, thus providing information about reading flow and finger movements (see Perea et al., 2015).

While all of these tools provide some stimulus control and customization, the prices can be quite steep. More importantly, they do not offer precise control over the timing of the presentation, as the participant actively moves their hand to perceive the stimuli. We can call them “finger-tracking” tools that somehow parallel eye-tracking devices for visual reading,

allowing researchers to analyze the reading movements. Nonetheless, they might not be the ideal tools for experiments focusing on word identification or those using electrophysiological techniques – which provide an excellent window into the time course of processing (e.g., event-related-potentials [ERPs]; see Grainger & Holcomb, 2009, for review). Because these devices do not control the hand and finger movements that individuals make while reading braille, response times are extremely variable (see Lei et al., 2019). Furthermore, hand movements may generate motor artifacts in electrophysiological measures, so finding/visualizing the underlying cognitive effects is challenging. Besides, some non-automated techniques have also been used to study braille reading, mainly via video recording the participants' hands while reading braille (e.g., Millar, 1997). Those techniques lack the *automaticity* requirement because they require the manual coding of video frames, potentially leading to human error and differences in results due to having different coders.

Researchers on texture perception have developed other tools that overcome some of the limitations of finger-tracking using *passive haptic perception*. Passive haptic perception refers to the perception mediated by variations in cutaneous stimulation and kinesthesia in which the perceiver does not have control over picking up stimulus information (Loomis & Lederman, 1986). For example, Avilés et al. (2010) developed a *Tactile Spinning Wheel* where different tactile stimuli fixed onto a rotating circular platform can be presented to the fingertips while controlling for spinning velocity and stimuli position. Oddo et al. (2011) designed a “mechatronic” device that slides stimuli through the finger-pad, controlling for sliding speed and indentation force. Similarly, Mounbou et al. (2016) created a robot that slides textures against the fingertip at a controlled speed. These texture perception tools that rely on passive haptic

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perception present limitations in terms of the *customizability* properties we look for in a system; besides, they use proprietary hardware that lacks *portability*.

To overcome these limitations, we have developed TouchScope, a passive-haptic-perception tool that can help researchers conduct experiments on braille reading, tactile perception, and haptic perception. This tool fulfills all requirements outlined above: 1) it allows the control of the timing of stimuli presentation; 2) researchers can customize trial parameters; 3) it employs passive haptic perception, allowing the display of stimuli through rubbing on the skin and controlling the hand/arm movements of participants, thus allowing more precise response times; 3) it avoids motor artifacts that may induce noise in cognitive neuroscience techniques (e.g., electroencephalography [EEG], magnetoencephalography [MEG], and transcranial magnetic stimulation [TMS]); 4) it presents stimuli in an automated manner; 5) it uses open-source software so it can be recreated in any other laboratory with no extra cost, and has a simple design that makes it portable. We hope that this device will improve our knowledge of the cognitive processes that underlie tactile/haptic phenomena by creating paradigms similar to those used in the visual modality.

TouchScope. The Device

Hardware

We developed a passive haptic reading tool with three main components: 1) a motorized linear bearing; 2) an Arduino Uno board with a motor shield; and 3) a refreshable braille display. Figure 1 shows a depiction of the physical components and their connections.

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The motorized linear bearing is constructed following Dring's (2013) simple camera slider project. (Footnote 1) Briefly, a stepper motor was attached to a 4-wheel carriage, which is placed on a rail. A toothed belt surrounding the rail is connected to the stepper motor, which transfers the motor's motion to the carriage, allowing linear movement. The use of a stepper motor is important because it enables precise positioning and velocity control since they divide the rotation into discrete steps. Here, we used a 200 steps/revolution stepper motor, an 18 teeth pulley, a 2mm pitch belt, and no microstepping factor (i.e., one full step per step). These specifications are essential to be able to set up the speed and distance we require. Last, on top of the motorized carriage of the linear bearing, we placed a refreshable braille display.

The motor is connected to an Arduino Uno board, an open-source ATmega328-based microcontroller board with 14 digital input/output pins plus six analog inputs, a 16-MHz crystal oscillator, a USB connection, a power jack, an In-Circuit Serial Programming header, and a reset button (Arduino.cc., 2020). The Arduino Uno board can be powered either from a USB connection or from an AC-to-DC adapter or battery. The board can operate on an external supply of 6 to 20 volts. Each of the 14 digital pins operates at 5 Volts and can be used as an input or output (D'Ausilio, 2011). Besides, an Adafruit Motor Shield is attached to the board to drive the stepper motor, controlling the speed, direction of movement, and distance.

As shown in Figure 1, the moving platform is connected to the Arduino Uno board through the motor shield (to which the stepper motor is wired); the Arduino Uno board is powered via an AC-to-DC adapter and connected to a MacOS computer through a USB cable. The macOS system was chosen because it has a built-in accessibility feature – VoiceOver – that allows communication with the refreshable braille display. (Footnote 2) Finally, the braille display is connected to a computer through a USB cable. As already mentioned,

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TouchScope can be used not only to examine braille reading, but also to explore any other phenomena related to tactile/haptic perception.

Software

TouchScope uses three pieces of software: 1) Arduino Integrated Development Environment (IDE); 2) an executable Bash script; and 3) VoiceOver. Both the Arduino IDE and the Bash shell are open-source software, with plenty of information available on-line, and the VoiceOver utility, as stated above, is a tool fully integrated into the macOS X operating system. Hence, there is no extra cost associated with the operation of TouchScope.

These three software elements are synchronized to control the platform's movement, stimuli presentation, and response recording. Specifically, through the Arduino IDE, we control the carriage speed (in rpm) and distance (in steps); and through the executable Bash script we can: 1) trigger the movement of the platform via communication with the serial monitor of the Arduino IDE; 2) present the trials on the screen via the computer terminal; 3) record the participants' data in separate files. The Arduino IDE code and Bash script are available in the Appendix.

To set up the speed and distance, we need to calculate our device's steps per millimeter. We can do that with the following formula:

$$\frac{\text{Steps per revolution} \times \text{microstepping factor}}{\text{Belt pitch} \times \text{Pulley teeth number}}$$

As stated above, we used a 200 steps/revolution stepper motor, an 18 teeth pulley, a 2mm pitch belt, and no microstepping factor. Hence, our TouchScope runs at 5.56 steps/mm. That is,

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35.9 mm/revolution (i.e., 200 steps per revolution/5.56 steps per millimeter). Of course, these numbers would change if any pieces are modified (e.g., using a 20 teeth pulley, which is more common than the 18 teeth one). These specifications are important pieces of information to determine the speed and distance we want the device to move.

In addition to the Arduino IDE and the Bash executable, we used the VoiceOver accessibility feature to send the stimuli from the computer terminal to the refreshable braille display.

Device Assessment

To offer an idea of the usefulness of TouchScope in the study of haptic/tactile perception, we designed a study that examined the perceived similarity of pairs of braille letters using a same-different task, common in studies of visual letter similarity (e.g., Courrieu et al., 2004; Podgorny & Garner, 1979; Wiley et al., 2016), with naïve braille readers (i.e., sighted readers with no prior knowledge of braille). Note that although braille letters are dot patterns for these participants, they can still identify if the two patterns (i.e., letters) presented in each trial are the *same* or *different* (see Wiley et al., 2016, for an experiment in the visual modality). To be able to assess TouchScope's value, we had two experimental procedures: some participants used the moving capabilities of TouchScope, hence doing the task via passive haptic braille perception (i.e., *passive procedure*), and others only used the stimulus presentation capabilities of TouchScope, thus moving their finger across the refreshable braille display (i.e., *active procedure*). Our main goal was to compare participants' performance between the two experimental procedures regarding accuracy and response time variability.

General Method

We employed a same-different judgment task. Participants used the index finger of their dominant hand to sense the braille stimuli and the middle and index finger of their non-dominant hand to make the *same-different* responses using the M and N keys of a computer keyboard, respectively. Note that these two keys are contiguous on most languages' keyboards to be pressed with two fingers of the same hand at no motor cost. For each trial, we presented two braille letters in the refreshable braille display. Participants perceived them serially (i.e., letter 1 before letter 2) from left to right and classified them, as fast and accurately as they could, as being *same* (e.g., $\begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix} \begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix}$) or *different* (e.g., $\begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix} \begin{smallmatrix} \bullet & \bullet \\ \vdots & \bullet \end{smallmatrix}$). To avoid that participants saw the stimuli being presented, the braille display (either by itself or on the developed motorized linear bearing – as TouchScope) was placed in the pull-out keyboard tray of the desktop. In contrast, the keyboard was placed on top of the desktop. Each braille display had 3D stickers separated 5 cm, indicating the area where the braille letters would appear.

Materials

The study used all possible 2-letter combinations: 676 pairs. Out of those pairs, 26 were the same two letters (e.g., $\begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix} \begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix}$), and 650 two different letters (e.g., $\begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix} \begin{smallmatrix} \bullet & \bullet \\ \vdots & \bullet \end{smallmatrix}$). Thus, five different lists of pairs were created in which 130 were *same* pairs (i.e., formed by the same two letters), and 130 were *different* pairs (i.e., formed by two different letters). Each participant perceived 266 trials, where 6 were practice and 260 were target trials; the order of presentation was randomized for each participant.

Active procedure: using the static mode of TouchScope

Participants. Ninety-one undergraduate students at DePaul University who did not know how to read braille were recruited through the subject pool system. They earned one course-credit for taking part in the study. All participants gave informed consent before the experiment. With this sample size, we wanted to ensure each pair of different letters was observed a minimum of 15 times (considering pairs containing the same two different letters in the opposite order as being different pairs [e.g., $\begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix} \neq \begin{smallmatrix} \bullet & \bullet \\ \vdots & \vdots \end{smallmatrix}$], and taking into account that some trials may be lost in data cleaning).

Procedure. The experiment took place individually in a quiet room. Participants were instructed to use the index finger of their dominant hand, in a continuous left-to-right motion, to touch the braille letters presented in the display, and to use the middle and index fingers of the non-dominant hand to make responses by pressing the *same* and *different* keys – M and N, respectively – in the computer’s keyboard. After touching the two letters once, participants had to classify them as being *same* or *different*. Inter-trial-interval (ITI) was one second—this allowed participants to reset the finger’s position (see Figure 2). Every time a new trial appeared on display, the dots' sound rising signaled participants to start the finger motion. The experiment took around 30 minutes to complete.

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Passive procedure: using the moving feature of TouchScope

Participants. A new sample of 86 undergraduate students from the same pool as in the previous experiment participated in the study. They also earned one course-credit for taking part in the study. All participants gave informed consent before the experiment. Again, ensuring each pair of different letters was observed a minimum of 15 times.

Procedure. The procedure was parallel to the previous experiment, except that participants used the moving version of TouchScope. Hence, participants did not move their fingers to perceive the stimuli. They were instructed to place their index fingertip on the start position to let the braille display slide against it. The braille display moved for 5 cm at 38.9 mm/s ($35.9 \text{ mm/rev} \times 65 \text{ rpm} / 60$). This speed was chosen considering previous studies on passive touch (see Vega-Bermudez et al., 1991), as well as our own experience testing it. After moving said distance, the display stopped until participants responded and reset its position during the one-second ITI. This experiment also took around 30 minutes to complete.

Results

All data wrangling and analyses can be found in the online appendix at <https://osf.io/tyzvp/>. Participants whose accuracy was below 51%, trials in which responses were either faster than 200 ms or slower than 12,000 ms, and trials in which the key pressed was other than M or N were excluded from the analysis. These criteria were established before data was collected (see Gomez et al., 2017). Less than 5% of the data were excluded from the analyses for both groups. Table 1 shows the mean accuracy, mean response times, and response time variability per procedure (active or passive) and trial type (same or different). We analyzed accuracy and latency data using (generalized) linear mixed-effects models in R (R Core Team, 2020) with the lme4 (Bates et al., 2015) and lmerTest packages (Kuznetsova et al., 2017). For both measures, the fixed-effect factors were Procedure (active, passive) and Trial type (same, different); Subject was the random factor. For the accuracy data, we employed the binomial distribution.

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Consistent with the central tendency measures shown in Table 1, overall accuracy did not differ between the procedure groups, $b = .065$, $SE = .069$, $z = .940$, $p = .347$. While accuracy was lower for different than for same trials, $b = -.143$, $SE = .070$, $z = -2.057$, $p = 0.040$, this difference was larger for the passive group than for the active group (8.1% vs. 14.0%, interaction: $b = -.289$, $SE = .044$, $z = -6.531$, $p < 0.01$). Response times were longer for the active group than for the passive group, $b = .013$, $SE = .013$, $t = 0.858$, $p < 0.01$. The other comparisons in latency data were not significant (trial type: $p = 0.254$; interaction: $p = 0.440$). More important for the present study's purposes, response time variability was substantially smaller for those perceiving the stimuli in a passive-haptic manner than for those perceiving the stimuli actively (SD = 0.902s vs. 1.563s; respectively. See Table 1). Therefore, data collected using the motorized (passive) version of TouchScope had less response time variability, and higher differences in accuracy at no cost in response times.

We also computed the Pearson correlation coefficient for the accuracy measures per trial between both procedures (i.e., active and passive). As can be seen in the scatterplot displayed in Figure 3, there is a strong linear association between the two data sets, $r = 0.761$ — note that each data point corresponds to a pair of braille letters.

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Discussion

The present article describes TouchScope, an easily reproducible system designed to control experiments on braille reading and tactile/haptic perception. To demonstrate its potential, we have shown that using the motorized mode of TouchScope in a same-different task does not

alter participants' accuracy and decreases the vast variability in response times relative to having participants actively move their fingers.

Furthermore, the static mode of TouchScope has also been shown to be a useful tool to examine tactile perception. To examine context effects in the tactile modality, Baciero et al. (in press) developed a tactile version of the well-known Flanker effect (Eriksen & Eriksen, 1974) using TouchScope to present the stimuli and record participants' responses. They simultaneously presented a target dot pattern (e.g.,) to participants' middle fingerpad, and distractor patterns to the adjacent index and ring fingers (i.e., congruent or incongruent with the target; e.g., , , , , ,). Participants had to identify the identity of the target stimulus by pressing the corresponding key on a computer keyboard. While there was a strong flanker effect in the tactile modality, its temporal dynamics differ from those results found in the visual modality, thus suggesting the cognitive mechanisms that underlie this effect are guided by both modality-general and modality-specific processes.

In sum, we have described the development of a tool that we believe offers researchers the possibility to design and conduct tactile research: 1) with reasonable control of the timing of presentation of the stimuli; 2) with a combination of behavioral and cognitive neuroscience techniques (e.g., recording electrophysiological measures); and 3) minimizing human errors related to the manual change of stimulus between trials. We believe that TouchScope will enable researchers to design novel techniques that measure response time to infer the cognitive mechanisms that underlie different tactile abilities. We hope TouchScope helps to expand tactile and haptic related research.

Open Practice Statement

The code used to program TouchScope's movement and data recording and the stimuli, data files, R code for data wrangling and analyses regarding the experimental study are available at <https://osf.io/tyzvp/>.

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Table 1. Descriptive statistics of participants' performance per procedure group (active and passive-haptic) and trial type (same and different). Note that response time is depicted in seconds (min = 0.2, max = 12).

Procedure	Trial Type	Mean Accuracy	Mean RT	Median RT	SD RT	RT distribution
Active	Same	0.775	3.551	3.184	1.593
Active	Different	0.694	3.530	3.195	1.531
Passive	Same	0.787	2.530	2.290	0.908
Passive	Different	0.647	2.525	2.293	0.897

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Figure Legends

Figure 1. Passive braille reading tool and connections. **A)** Arduino Uno board and Adafruit motor shield. **B)** Motorized linear bearing. **C)** Refreshable braille display.

Figure 2. Diagram of a *different* trial in the same/different judgement task. Stimuli perception was done with the index finger of the dominant hand, and responses with the non-dominant hand.

Figure 3. Scatterplot of the active and passive procedures. The x-axis shows the distribution of mean accuracy in the active condition and the y-axis shows the distribution of mean accuracy in the passive condition. Each data point represents a pair of letters, and the gray area represents the ± 1 SE.

Footnotes

1. The step-by-step instructions are available at:
<https://www.inventables.com/projects/simple-camera-slider>.
2. There is also free software for Windows: NVDA; although it is not built in the system. The version of the Mac OS in which the software's device was implemented is Mojave.

Appendix

Arduino IDE code:

```
// Install serial communication between bash shell and Arduino IDE: brew.sh
// Install libraries for motor control (Adafruit Motor Shield) & for serial communication
// ( advancedSerial) under "Sketch" in toolbar
// Chech board ("Arduino Uno") and port (/dev/cu.usbmodem...) under "Tools" in toolbar
```

```
#include <Wire.h>
#include <Adafruit_MotorShield.h>
#include "utility/Adafruit_MS_PWMServoDriver.h"
Adafruit_MotorShield AFMS = Adafruit_MotorShield();
Adafruit_StepperMotor *myMotor = AFMS.getStepper(200, 1);
void setup() {
  Serial.begin (9600); // Arduino ready to exchange messages with Serial Monitor at 9600
  bits/second (baud rate).
  pinMode (LED_BUILTIN, OUTPUT);
  AFMS.begin(); // create with the default frequency 1.6KHz
  digitalWrite(LED_BUILTIN, HIGH);
}
void loop() {
  int movement = Serial.read();
  if (movement == '1') {
    myMotor->setSpeed(7000); //rpm
    myMotor -> step(200, FORWARD, DOUBLE);
  }
  else if (movement == '2') {
    myMotor->setSpeed(65);
    myMotor -> step(200, BACKWARD, DOUBLE);
  }
}
```

Bash Shell script (no movement):

```
# setup a new data file (e.g., one per participant)
echo "data file name (no spaces)"
read datafile;
# Exp Variables
echo "enter ITI in seconds" #inter-trial interval
read ITI;
echo "enter stimuli file name" #stimuli list
read path;

echo " ";
sleep $ITI;

# Send tidy data to the datafile ">" creates the file. The column name is the following line
between quotations
echo "IT1 IT2 KEY RT" > "$datafile"
IFS=$'\n' #new line

for p in `cat "$path"`; #loop
do

ITEM="$p"; #show trial
clear;
start=$(gdate +%s.%N); #timer
read -n 1 -s -r -p "$ITEM" KEY; #read key pressed
RT=$(echo "$(gdate +%s.%N) - $start" | bc); #response time
printf "$ITEM $KEY %.3f\n" $RT >> "$datafile"; #save
clear;
sleep $ITI; #wait inter-trial interval

done
```

Bash Shell script (with movement):

```
# setup a new data file (e.g., one per participant)
echo "data file name (no spaces)"
read datafile;
# Exp Variables
echo "enter ITI in seconds" #inter-trial interval
read ITI;
```

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```
echo "enter stimuli file name" #stimuli list
read path;

echo "  ";
sleep $ITI;

# Send tidy data to the datafile ">" creates the file. The column name is the following line
between quotations
echo "IT1 IT2 KEY RT" > "$datafile"
IFS=$'\n' #new line

for p in `cat "$path"`; #loop
do

ITEM="$p"; #show trial
./arduino-serial -b 9600 -p /dev/cu.usbmodem1411 -s 2 %> /dev/null; #send a "2" to Arduino
Serial Monitor
clear;
start=$(gdate +%s.%N); #timer
read -n 1 -s -r -p "$ITEM" KEY; #key pressed
RT=$(echo "$(gdate +%s.%N) - $start" | bc); #response time
printf "$ITEM $KEY %.3f\n" $RT >> "$datafile"; #save data
clear;
./arduino-serial -b 9600 -p /dev/cu.usbmodem1411 -s 1 %> /dev/null; #send a "1" to Arduino
Serial Monitor
sleep $ITI; #wait inter-trial interval

done
```