# An Objective System for Quantifying the Effect of Cognitive Load on Movement in Individuals with Autism Spectrum Disorder

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***Abstract*— It is common to isolate a single task in laboratory studies, but the reality of our everyday experience is that we engage in multiple tasks simultaneously, e.g. walking while talking (or texting) on our phones. We designed a system composed of three task types and accompanying hardware to simultaneously quantify balance, fine motor skill, and cognitive ability. We hypothesized that the additional demands of the balance and speeded finger-tapping tasks would degrade motor performance in the simultaneous conditions, but not impact cognitive (N-Back task) performance. Movement data were evaluated by comparing the change of each group across 3 levels of cognitive load (0-, 1-, and 2-back). We tested the task on a small sample of young adults with autism spectrum disorder (ASD) and matched controls. We observed a trend largely consistent with our hypotheses. The system's temporal precision and modular design also allow for the incorporation of other sensors as needed, like EEG or heart rate variability. We propose that a version of this system be tested as a putative outcome measure for interventions involving attention capacity, cognitive load or certain types of motor skill training.**

## I. INTRODUCTION

Autism spectrum disorder (ASD) is a developmental disorder defined by the presence of functional difficulties in communicating and social interaction as well as repetitive behaviors and restricted interests [1]. According to the Centers for Disease Control and Prevention, the amount of people diagnosed with Autism has risen dramatically over the past five years [2], creating a need for better methods for assessing symptoms and their improvement after intervention.

Two frequently overlooked and likely related aspects of ASD are difficulties with attention and movement control. [3,4]. Research has established the existence of deficits in attention, postural sway, gait, and rhythmic tapping performance in both younger and older participants with ASD [5]. Since multiple lines of evidence suggests that there exists a shared pool of resources for attention and motor tasks [6, 7], we sought to create a task that assessed these skills both alone and in combination. We aim to design a task which can be broadly used as a robust assessment and possibly also an outcome measure to evaluate the success of attention interventions.

We tested unbiased movement control in association with various amounts of cognitive load. We coupled a vocally triggered N-back task with two simple movement conditions: standing balance and finger tapping. We selected the N-back task due to its effects on working memory and attention and previous results suggesting differences in the ASD population [8]. Gathering unbiased data directly related to the difficulty of the N-back was accomplished by selecting movements that engage minimal cognitive load when performed alone. We do not expect to see any significant differences in either group's performance of the task [9].

Balance skills are needed for everyday functioning. We hypothesize that the sensorimotor activation demanded for eyes open, dual stance balance will be impacted by large cognitive loads. We used a forceplate to detect subtle Center of Pressure (COP) movements during standing balance performed alone and during the N-back task. COP will fluctuate mediolaterally and anteroposteriorly and can be interpreted by analyzing the standard deviations of both directions [10].

Finger tapping is a more consciously activated motion than standing, but much like standing, we hypothesize it also will engage minimal cognitive load when performed alone, but will amplify the impact of the cognitive load induced by the N-back on balance. We also expect to observe increased variability in inter-tap interval under increasing cognitive load. For this purpose we designed a custom glove with conductive cloth on the tips of the forefinger and thumb that closes a circuit when the thumb and forefinger pinch together.

Using this suite of synchronized sensing hardware and cognitive task, we ran a small pilot experiment with young adults on the autism spectrum and typically-developed individuals of matched age.

## II. METHODS

### A. Participants

Eight people participated in this study (mean age: 21.5 $\pm$ 1.5, 50% Typically Developing, 50% self-identify on the Autism Spectrum). All participants were right-hand dominant with normal or corrected vision. All participants signed an informed consent sheet verified by the University of California, San Diego Human Research Protections Program.

### B. Protocol

After completing a standard Wechsler Abbreviated Scale of Intelligence test (WASI II). Participants were asked to remove their shoes and stand on a forceplate facing a monitor display positioned at eye level. They were asked to stand up straight and to try to move as little as possible

*This work was supported by NSF #1640909

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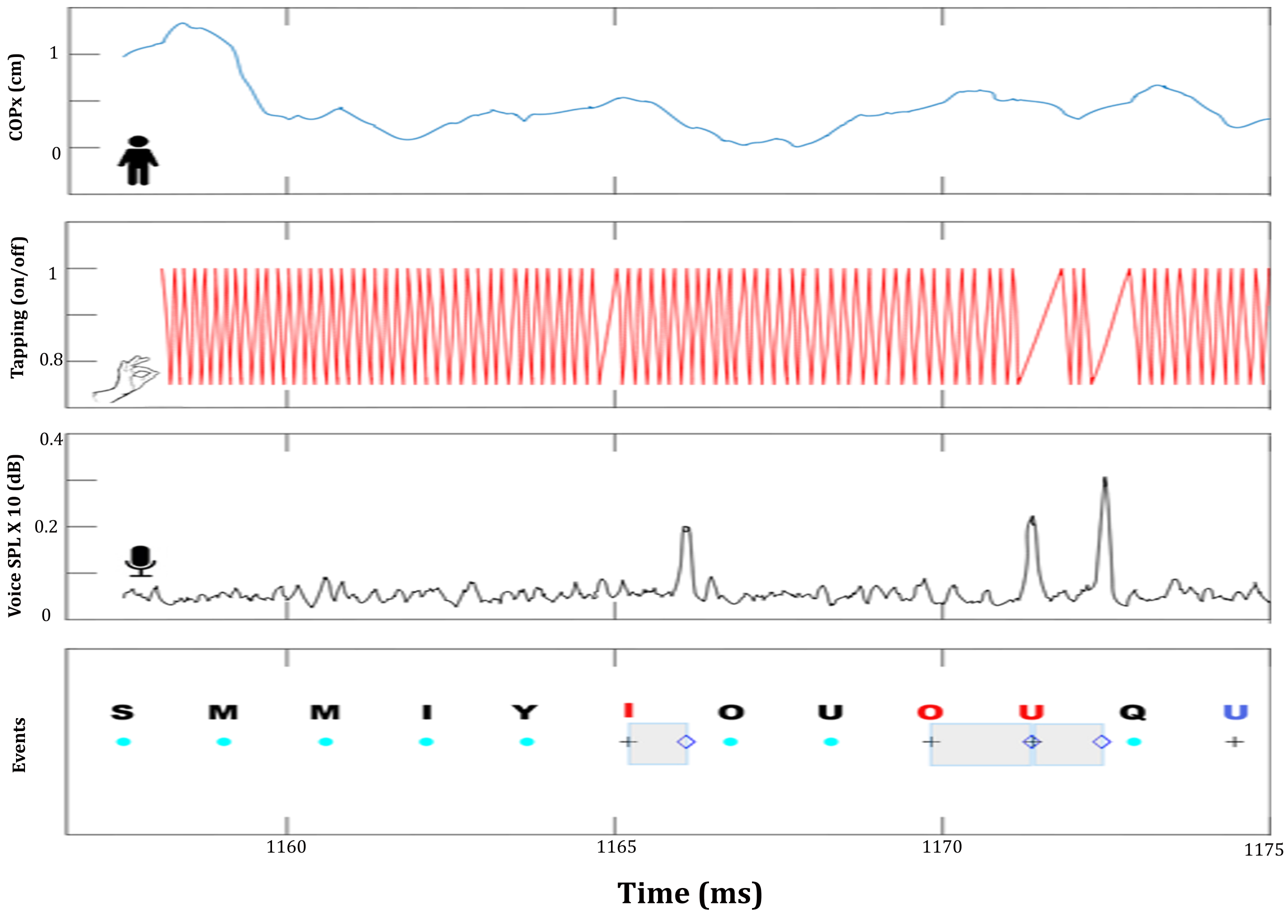


Fig. 1. Example data of an excerpt from a 2-back trial all aligned on trial time. Top panel shows the center of pressure excursion data from the forceplate for the x-axis. Second panel shows finger-tapping performance with touch onset defined as 1 and touch offset defined as 0.75. The graph illustrates the mostly regular nature of the data, with some irregularities. Third panel shows microphone data captured during the N-back task. Large excursions mark the subject voicing "Now" to mark a match in the task. Fourth panel shows the sequence letter events appearing on the screen in front of the subject. The red letters indicate a correctly identified 2-back match. The blue letter indicates a missed 2-back match. The time interval between the plus sign and the diamond indicates a subjects reaction time.

while completing the task. Tapping was performed with the dominant hand out in front, with the elbow bent. Execution of the cognitive N-Back task was explained and practiced first with an examiner until confirmation of understanding was achieved. All actions were verified for correctness by an examiner before stepping into an adjacent examination room. The participant was left alone in a testing room with vocal access to the examiner at all times. Participants first performed two 35 second baseline tasks of static standing and tapping respectively. After which, six blocks (2 of each difficulty) of an N-Back task were given sequentially, followed by the same blocks with the added condition of finger tapping.

### C. Cognitive Task Design

The cognitive task design implemented the N-back task where a sequence of letters appeared on the screen at a constant speed (500ms display, 1000ms gap between letters). Three conditions increased the cognitive load on the participants: 0-, 1-, and 2-back. In the 0-back task participants respond whenever the letter is an 'X,' and otherwise they do nothing. In the 1-back task the participants respond if two letters are the same; for example, the sequence 'A, A' should be responded to, but 'A, B' should not. In the 2-back, memory is challenged even more by asking participants to respond if and only if the current letter is the same as the one shown 2 iterations ago. For example, 'A B A' should be responded to since the 'A' repeats, but 'A B B' should not. No feedback was provided during the task, but after every block of 24 letters, a block of 3-5 animated stars indicated performance. In each block of 24 letters, there were exactly 8 that met the N-back requirement for the block. Two responses are possible depending upon if the letter presented warrants a vocal response. The participant can give 1) Correct Response (CR): correctly vocalizes in response to a letter 2) Correct Non-Response (CN): correctly does not vocalize in response to a letter 3) Incorrect Response (IR): incorrectly vocalizes in response to a letter 4) Incorrect Non-Response (IN): incorrectly does not vocalize in response to a letter

Since participants tapped their fingers in some conditions, they used their voice to indicate a match in the N-back. Participants wore a standard microphone headset that reported the monitor level to the recording software. When the monitor crossed a threshold, an event signaled a response. The raw monitor data were also recorded. The participants spoke the word 'Now' when they wanted to indicate a response.

### D. *Movement measures*

A custom glove recorded the time when the forefinger and thumb came together (a tap). To automatically detect finger taps, we sewed ~4cm$^2$ pads of conductive cloth (70% polyester, 15% copper, 15% nickel) onto the tips of the thumb and forefinger of a cotton glove. We sewed conductive thread along the back of the finger and thumb to a port at the back of the hand. A 2 meter wire connected the two conductive pads to a pull-down switch on a digital I/O pin on a Teensy LC (Arduino compatible). The Teensy LC was programmed to report the state of the pull-down switch when polled over a serial connection. We wrote a Vizard 4.0 script to poll the glove every 16ms (60Hz). Participants always wore a separate latex glove under the cotton glove during performance to maintain cleanliness.

Center of pressure data were recorded with an AMTI forceplate using previously created software compatible with Vizard 4.0 and verified to introduce less than 6ms of latency, and sub-millimeter precision [5]. Early trials indicated that the static stance did not challenge the participants, so we placed a ~6cm thick foam pad (Airex BeBalanced Balance Pad) on top of the forceplate. All participants wore thin socks.

## III. RESULTS

### A. *Cognitive task*

Although N-Back tasks are an established form of working memory assessment, our vocally triggered iteration is novel. Since our data is consistent with performance from more traditional N-Backs, our version could be useful for research that requires the use of your hands. N-Back task results were analyzed based upon correctness and reaction time. As hypothesized, the data from both the Control and ASD groups were indistinguishable from each other. Due to the simplicity of the 0-back and 1-back conditions, only in the 2-Back condition did we find changes in reaction time and amount of incorrect responses. Correct responses (0-Back = 97.7(8)%, 1-Back = 98(2)%, 2-Back = 92(2)%) declined in the 2-Back by 6(3)%). Although this is a substantial drop in performance, participants become much more comfortable with the task by the end of testing. It could be possible that a harder task (e.g. 3-Back) is needed to fully understand how cognitive load affects movement.

### B. *Finger Tapping*

Tapping was analyzed according to the participants inter-tap interval (ITI) performance. Control group ITI mean is 0.191(9)s, and ASD is 0.223(9)s. The ASD group trend toward a longer inter-tap-interval ($t(6) = 2.01, p = 0.09$, Figure 2). In figure 2 one ASD individual shows ~50ms longer inter-tap-interval than the next slowest. That individual's standard deviation of ITIs was consistent with the others, denoting that their tapping rhythm was within an acceptable range. We instructed participants to tap as fast as they could for the 30 second duration of each block. Enough rest was given after each block for participant's to recover. No complaints of fatigue were ever given or observed.

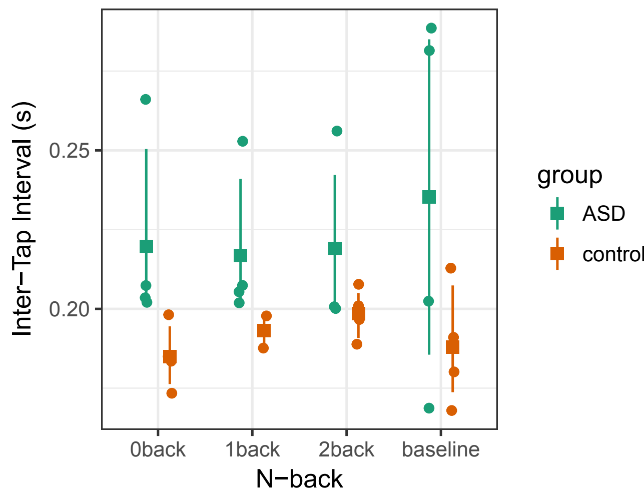


Fig. 2. Inter-Tap-Interval (The time in-between touches, ITI) data from ASD (green) and control (orange) groups across each of the three N-back (0back, 1back, 2back) conditions, and also including the baseline. Small circles represent the individual participant mean. Squares represent group means. Lines are 95% confidence intervals.

### C. *Standing Sway*

Quiet, stationary stance shown below (Figure 3) illustrates the standard deviations for COP movement across the mediolateral plane. The COP from each group was extremely similar as a whole along the X-axis. ASD group mean is 1.1(1)cm and the Control group mean is 0.7(8)cm. Tapping trials also did not show any differentiation from non tapping trials. Tapping is 0.9(1)cm and no tapping is 0.9(1)cm. Neither task difficulty nor the addition of tapping affected quiet, stationary stance.

### D. *Integrative data*

In order to understand the effects of the N-Back task in greater depth, we gathered data based on the individual N-Back vocal responses. We sorted the finger tapping data in accordance to each individual response category. Triggered at the start of a trial (the presentation of a letter on the monitor), finger tapping would be recorded for 2 seconds after and sorted into 1 of 4 categories depending on the participants correct or incorrect presence or absence of response. Due to participants achieving a high percentage of correct responses/non-responses, we do not yet have enough substantive data to make any assertions of incorrect responses/non-response in any regard. However, (Figure 4) for all 3 N-Back Conditions and 2 Response categories, Typically Developing

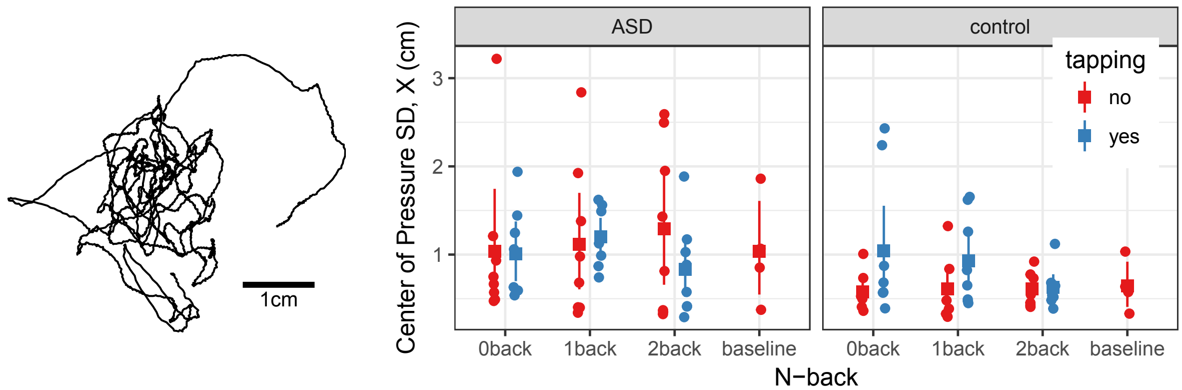


Fig. 3. Standard deviations for Center of Pressure (COP) movement (example of trial on the left) along the X-axis. (Right) Each group is separated by N-Back condition(y-axis). Tapping trials are indicated by color (red = no tapping, blue = tapping). Square markers represent the group's mean with attached error bars showing 95% confidence intervals. Circle markers indicate the individual participant's mean.

participants produced significantly lower response triggered ITIs than the ASD group. ASD mean ITI is 0.223(9)s and the Typically Developing ITI mean is 0.191(9)s (CN group $t(6) = 3.20, p = 0.019$: CR group $t(6) = 3.08$, $p = 0.022$). Changes across N-Back condition we not significant, however this could be due to low sample size or a need for a more challenging task.

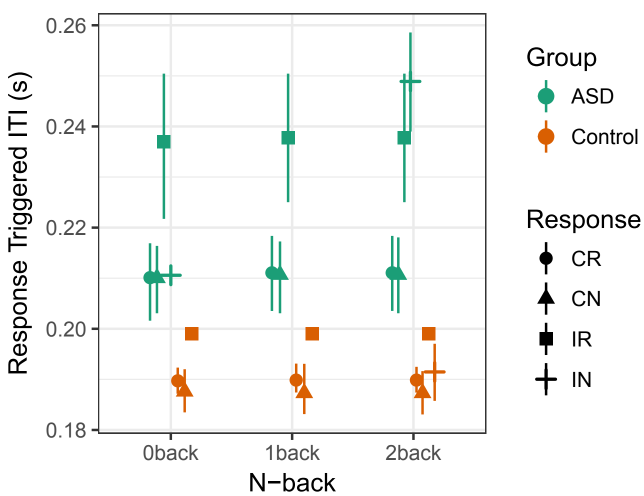


Fig. 4. Response Triggered Inter-Tap-Interval of ASD (green) and Typically Developing (Orange) group-sorted ITIs across N-Back conditions (mean and 95% conf.). In response to a letter, participants were either correct or incorrect (C or I) and either responded or not (R or N). The tapping is rhythmic with low variability, except after mistakes (IR or IN), when both groups slow their tapping and are more variable.

## IV. CONCLUSIONS

We designed a cognitive-motor task to explore the interplay between cognition and movement and test hypotheses about how this interplay may be different in ASD. In this proof-of-concept study, we demonstrated that we can record data from multiple streams in real time: voice, stance, finger tapping, and task performance. Preliminary analyses indicate that individuals with ASD tapped their fingers more slowly than controls, and both groups tapped less rhythmically when the cognitive load was high and especially when they made mistakes in the cognitive task. As we scale up the study, it will be useful to increase the cognitive task difficulty and introduce additional devices, such as EEG or a heart rate monitor.

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