Validity and feasibility of a tri-axial accelerometer for measuring an upper limb Fitts' Task

by

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Abstract

Background: Devices used to display and record Fitts' task performance typically lack portability and accessibility outside the laboratory environment. Touch-based interfaces, while more portable, cannot yield many secondary measures of interest. A portable acceleration- and touch-based equipment package was developed to facilitate the application of the Fitts' task in remote environments.

Purpose: To validate a novel portable acceleration and touch-based hardware and software package which can assess both primary and secondary Fitts' task performance measures.

Methods: Participants (N=22) set up the equipment and tested themselves remotely with live video support. Protocols from Glazebrook et al. (2015), which measured a violation of Fitts' Law using gold-standard equipment, were replicated. Groups of three closely spaced target placeholders were displayed. Participants touched the one filled-in target placeholder. Two measurement methods, touch and acceleration, were compared using linear regressions performed on movement onset and movement offset. Statistical results from both measurement methods were compared categorically to results from Glazebrook et al. (2015).

Results: The findings of Glazebrook et al (2015) were replicated using the novel portable acceleration and touch-based equipment. The touch and acceleration methods of measuring movement onset and offset were significantly correlated ($p<0.001$).

Conclusions: A portable acceleration method of measuring the Fitts' task was validated as: 1) it provided similar results to a touch-based method, but with richer secondary data; and 2) it replicated the findings of Glazebrook et al. (2015), which used gold-standard equipment. An alternate hypothesis concerning the cause of the violation of Fitts' Law is discussed.

Acknowledgements

I would like to thank my advisor, Steven Passmore, for finding promise in me and taking me under his wing for these last 7 years. I would also like to thank Cheryl Glazebrook, who has stood beside Steve as a second advisor to me for much of the time through my undergraduate and Master's degrees. I am thankful to the other members of my committee, Brian MacNeil and Jon Singer, who agreed to be a part of this work and have been wonderful to work with both on this and other projects. I am also grateful to the Canadian Institutes of Health Research and IG Wealth Management, who provided funding so I could complete my Master's degree.

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Introduction

What is Fitts' Law?

The Fitts' Task is one of the most well studied experimental paradigms in motor control literature. From when it was first described, both in its rhythmic (Fitts, 1954) and discrete (Fitts & Peterson, 1964) forms, it has been a valuable tool for providing insight into the function of the human motor system. Fitts' Law describes the trade-off between speed, or how fast one can reach a target; and accuracy, or how close to the center of a target one is able to contact. If speed is increased, then accuracy must be sacrificed as noise in the motor system will cause uncontrolled trajectory changes. If accuracy is prioritized speed must be reduced as online motor systems need time to assess error and thus enable corrections. It is only at the intersection of these two goals, where the individual tries to be both as accurate and as fast as possible, where Fitts' Law is evinced (Schmidt et al., 2019).

Fitts' Law describes the relationship between movement time (MT) and the characteristics of an objective target when a participant is asked to point to the target as quickly and accurately as possible. Movement time is the time from when the participant starts to move off the home position (their starting position for each trial) to when they land on the objective target. The characteristics that describe the target are the amplitude (A), which is the distance from the home position to the presented target, and the width (W), which is the diameter of the presented target in the axis parallel to the primary movement (i.e. in the same direction the amplitude is measured). Fitts' Law, as originally formulated (Fitts, 1954; Fitts & Peterson, 1964) is;

$$MT = a + b\ (ID) \qquad \textit{Equation 1}$$

The constant *a* (the y-intercept) and the coefficient *b* (the slope of the regression line), are participant and population specific. While *a* remains difficult to interpret, *b* is often thought to represent the efficiency of a participant's motor system (Schmidt et al., 2019), and essentially represents the sensitivity of the motor system to changes in ID. The Index of Difficulty (ID) integrates the relationship between *A* and *W* into the equation;

$$ID = \log_2 \frac{2A}{W} \qquad \textit{Equation 2}$$

The protocol that facilitates the Fitts' Law model is called the Fitts' Task, of which there are two types. The first is the rhythmic Fitts' Task, where two targets are presented at distance *A* apart and participants are asked to tap between the targets until a time limit is reached. The second type is the discrete Fitts' Task, where a single target is presented at distance *A* from a consistent starting position and the participant makes a single movement to the objective target from the starting position before resetting. Both are accurately modelled by *Equation 1*, with around 95% of the variation in MT being explained by changes in ID (Plamondon & Alimi, 1997).

An Information Theory Interpretation of Fitts' Law

Information Theory is a framework commonly used to interpret Fitts' Law. A $\log_2(i)$ component in an equation is held to be the amount of binary information (i.e. answers to a series of 'yes or no' questions) needed to have perfect information about a question with *i* possible answers. In a Fitts' Task, the ambiguity about which 'choice' to make, or where and how to aim the pointing limb, is considered to be caused by noise in the motor system (Crossman & Goodeve, 1983). Without any noise, an individual would be able to push themselves to be as quick as physically possible without sacrificing accuracy as they would be able to predict exactly where their initial ballistic movement would land their pointing implement. With motor system noise, online corrections of uncertain size and direction must be made after the error-prone primary ballistic movement to accurately contact the target. As the amplitude of the movement increases, the effects of noise will increase proportionally as any angular error in the initial movement will have a greater impact on linear error as displacement increases. These corrections are also online processes, which require time to assess and make. If a movement is anticipated to need a correction, the movement must be made slow enough that any error has enough time to be identified by online systems and the correction made by the end of movement (Crossman & Goodeve, 1983; Keele & Posner, 1968). Greater target amplitudes increase the distance travelled, amplifying the effects of any noise, and smaller target widths require that any online corrections be proportionally accurate, slow, and to possibly require corrections themselves if made too hastily. Therefore, at greater amplitudes greater corrections must be made and thus time taken. Small amplitudes may require no correction, allowing speed to be maximal. Medium amplitude movements may require small corrections that require little additional time to make.

The slope of *Equation 1*, *b*, can be interpreted as the efficiency of the motor system. It is the sensitivity of the motor system to changes in amplitude and width. A greater *b* means the motor system is more sensitive to changes of amplitude and width, responding with a greater MT to a target of a given ID than an individual or group with a lower *b*. An individual or group with a greater *b* may be then said to have a less efficient motor system, as more time is required to reach any given target than an individual or group with a lower *b*.

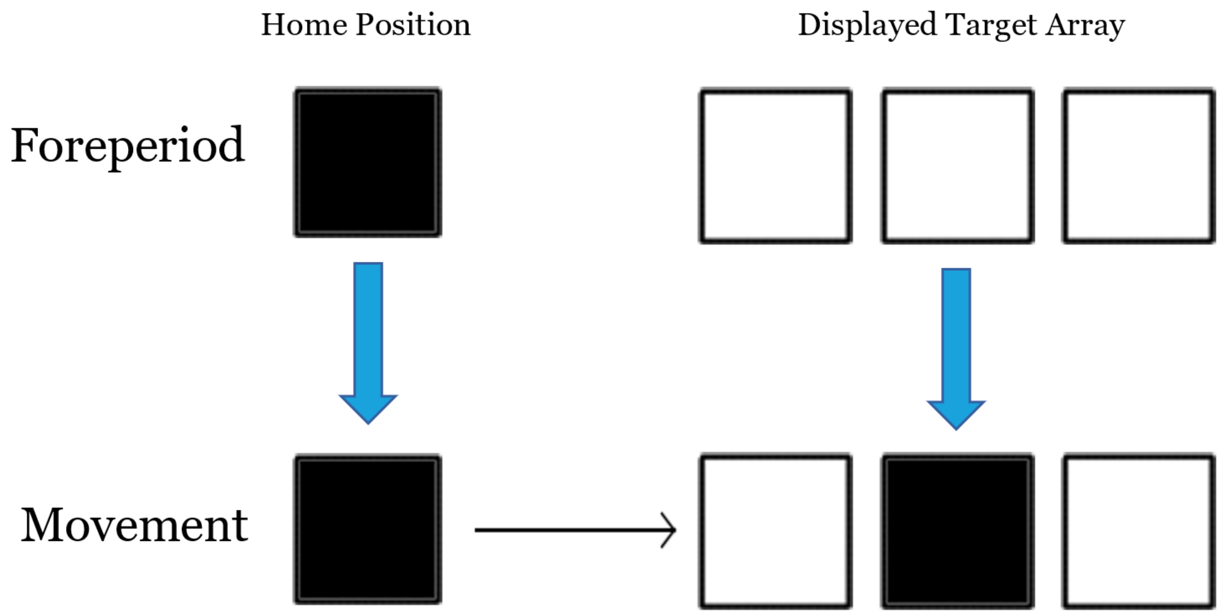
Violations of Fitts' Law

While Fitts' Law holds for a variety of populations and configurations, there are some specific scenarios where *Equation 1* fails to accurately predict MT. One of these so-called 'violations' of Fitts' Law takes place when possible targets are closely spaced and placeholder targets, which are displayed at all the possible locations a target could appear for that trial, are presented before and during movement (Figure 1). This configuration results in MT to the final two positions in the array being not significantly different from each other or MT to the final target being less than to the penultimate target (Adam et al., 2006; Blinch et al., 2012; Bradi et al., 2009; Glazebrook et al., 2015; Pratt et al., 2007; Radulescu et al., 2010).

There are two hypotheses that describe why this violation occurs, though neither hypothesis precludes the validity of the other. The first is the planning hypothesis, which posits that having potential target locations perceptively available during movement planning changes the strategies used in the movement. Specifically, the strategy changes to undershooting the final target in the array, with secondary movements making up the deficit if the final target were to be displayed. This then results in similar MT to the furthest and penultimate targets, as the same movement plan is used for both with just a small additional secondary movement used to reach the final target (Glazebrook et al., 2015). The second hypothesis is the online control hypothesis, which suggests that the end targets of the array act as 'anchors' of a perceived gestalt representation of the target array. Visual information of these anchors is processed faster than for other target locations and therefore online feedback can be used more quickly and efficiently, making movement to the furthest target as quick as to the penultimate target (Blinch et al., 2012).

Figure 1: Display configuration required for a violation of Fitts' Law

Figure 1: Display configuration required for a violation of Fitts' Law



No study has conclusively proven either hypothesis, though evidence to date favours the planning hypothesis. Experiments designed to parse the contribution of the two hypotheses have found that measures of movement planning, such as peak velocity, are significantly altered depending on the relative position of an outlined target compared to other outlined targets in the same trial (Blinch et al., 2012; Bradi et al., 2009; Glazebrook et al., 2015). However, the locus of the violation is within the secondary movements (Blinch et al., 2012), suggesting at least some online process must contribute to the violation. It seems as if the performer must plan to alter their secondary movements to facilitate the violation.

Fitts' Law and Physical Disability

The variable *b* has been examined, directly or indirectly, in a variety of groups with compromised motor systems as compared with healthy motor systems or asymptomatic limbs, including older adults (Goggin & Meeuwsen, 1992; Passmore et al., 2007; Pohl et al., 1996;

Walker et al., 1997; Welford et al., 1969), individuals with lumbar spinal stenosis (Passmore et al., 2014, 2015), individuals with neck pain (Descarreaux et al., 2010), individuals with stroke (Aloraini et al., 2019), individuals with cognitive impairment (Poletti et al., 2017), individuals with ataxia (Corben et al., 2011), individuals with unilateral nerve root compression (Sargent, 2019), and obesity (Gaul et al., 2018). For all these conditions, significant differences have been found in secondary kinematic measures and likely in *b*, considering the greater MT values that have been found as ID increases.

A related task paradigm which may be considered a simplified Fitts Task, the 'finger-nose task,' has been used and validated as a diagnostic tool for neurologists (Desrosiers et al., 1995; Gagnon et al., 2004; Raymond et al., 2017). The finger-nose task identifies patients affected by stroke (Desrosiers et al., 2006), ageing (Desrosiers et al., 1995), concussion (Schneiders et al., 2010), ataxia (Gagnon et al., 2004), and other movement-affective disorders. It is also used to track rehabilitation progress for many of these conditions. To begin the task, the testing clinician holds their hand near the patient's face while the participant touches their nose. The participant must reach from their nose to the clinician's hand, then back as many times as possible within a space of time, after which the count can be compared against normative values. Differences in the number of touches between symptomatic and healthy patients have been interpreted to result from the influence of pain or impacted neurons on the ability to move optimally. Pain or other factors cause the motor system to have greater error when executing a movement. Symptomatic patients therefore take a greater time to move compared to healthy individuals to allow time for online systems to correct for greater movement errors.

The Fitts' Task may therefore be useful as a screening, tracking, and diagnostic tool for physical disabilities that result in decreased movement ability (Passmore, Johnson, et al., 2019).

Most tools currently used for the purposes of assessing spine pathology rehabilitation progress are subjective ones, such as participant-filled questionnaires (Andronis et al., 2017; Bussières et al., 2016, 2018; Qaseem et al., 2017). While these tools have been validated, they are open to bias and manipulation by participants aiming to artificially alter diagnoses and the scores on these tools can change significantly day-to-day depending on factors such as the patient's mood. The objective measures that are currently used are of a set difficulty and/or are specialized for a certain pathology. The Fitts' Task is difficult to manipulate without being detected (Deuble et al., 2016), performance is consistent over time without an intervention (Plamondon & Alimi, 1997), and it has a modifiable difficulty, allowing adjustment to the needs of any participant (Aloraini, 2019; Aloraini et al., 2019; Guadagnoli & Lee, 2004; Passmore, Johnson, et al., 2019). The task may therefore prove to be an objective and versatile tool to assess and track physical disability.

Equipment Used to Conduct a Fitts' Task

The steps for integrating the Fitts' Task as a clinical tool include testing it on a wide variety of conditions causing motor disabilities, validating it against a wide variety of interventions for those conditions, and collecting population-specific normative data. An obstacle to proceeding with this process is the cost associated with the equipment used to measure the Fitts' Task. For several published Fitts' Task studies concerning symptomatic populations, an active position tracking system was used (Aloraini et al., 2019; Descarreaux et al., 2010; Glazebrook et al., 2015; Passmore et al., 2007, 2010, 2014, 2015; Passmore, Johnson, et al., 2019; Sargent, 2019). This method offers superior accuracy and temporal resolution, typically sampling at or above 300Hz and capable of much higher, with millimeter or better accuracy (Northern Digital Inc., 2020). These systems often cost between $50 000 and $100 000 CAD, putting it out of reach for many clinicians. The equipment is also bulky, with a 3D Investigator tower, a commonly used optical position tracking system, measuring 1126mm x 200mm x 161mm (Northern Digital Inc., 2020); difficult to fit in often confined clinical environments. Other methods of measurement, including touch-based digitization (Adam et al., 2006; Bradi et al., 2009; Goggin & Meeuwsen, 1992; Pratt et al., 2007; Radulescu et al., 2010; Sleimen-Malkoun et al., 2012) and electromagnetic plates (Fitts, 1954; Fitts & Peterson, 1964; Kvalseth, 1977) have their own respective drawbacks. Touch-based digitization either restricts movement to a 2-d plane, capturing kinematic measures but sacrificing ecological validity; or sacrifices kinematic measurement by allowing movement off the screen and achieving greater ecological validity. Electromagnetic plates cannot capture kinematic measures at all. As kinematic measures, such as peak velocity (Glazebrook et al., 2006; Passmore et al., 2015), time to peak velocity, (Glazebrook et al., 2006; Passmore et al., 2014, 2015), and peak acceleration (Glazebrook et al., 2006), have been observed to be affected by various health conditions when participants perform the Fitts' Task, they should be considered integral measures because they may enhance or enable the screening, diagnostic, and tracking capabilities of the task.

Digital Accelerometers

To facilitate clinical adoption, the Fitts' Task requires a low-cost measurement method which offers sufficient sampling resolution, programmatic control, and measurement of secondary outcome measures. Analog accelerometers are a possibility, having been used to supplement optical position systems (Passmore, Gelley, et al., 2019), and have been verified for use as a replacement for optical position sensors for acceleration, velocity, and displacement (Hansen et al., 2007). However, expensive analog-to-digital conversion boards (A/D boards) are needed to allow analog accelerometers to integrate with computing devices. There are microcontrollers and other less expensive devices which can convert analog readings to digital samples but typically only offer bit depths up to 10bits, which may be insufficient. Digital accelerometers would offer similar functionality to analog accelerometers when paired with a microcontroller while being inexpensive; 12bit digital accelerometers can be bought for less than $50 CAD, providing 4x the resolution of an analog accelerometer paired with a 10bit A/D board. Digital accelerometer-microcontroller systems have been used before to analyze human movement, including as a supplement to optical systems (Ortega-Palacios et al., 2015), as a stand-alone gait analysis system, (Fullante et al., 2017), and to determine response latency (Schubert et al., 2013). These studies have all shown that systems integrating these digital accelerometers and microcontroller technologies hold great potential for analyzing human movement in a compact and affordable modality.

A digital accelerometer/microcontroller device can be adapted to yield all outcome measures desired from a Fitts' Task. The only supplement such a device would potentially need would be a device to display targets and possibly measure endpoint position. Many approaches can be used to provide these functions, including using physical targets, using inexpensive screens connected to inexpensive computers to display targets, or using touch screens to display targets and measure endpoint position.

Objectives and Hypotheses

A digital accelerometer/microcontroller device may thus serve as a sufficient measurement method for Fitts' Tasks in clinical environments. A package making use of a digital accelerometer and microcontroller integrated with a target display and data analysis program has been developed (the Device). The primary objective of the present study was to validate the Device against known effective equipment and analysis methods. Unfortunately, due to the COVID-19 pandemic, in-person testing directly comparing measurements of the same movement from both the Device and the gold-standard equipment was unfeasible. An alternative to a straightforward validity test against the current gold-standard, an optical position tracking system, was a form of ecological validation; to replicate a previously published study using the Device and compare the yielded results to those in the published study. The Device made use of a touchscreen, so movement time and reaction time measured using the accelerometer were able to be compared to measurements taken with the touchscreen, allowing validation against previously used equipment (see section 1.5). University regulations concerning the mitigation of the impact of the pandemic by restricting in-person testing required remote testing, which presented an unexpected opportunity to examine the feasibility of the Device by requiring participants to set up and operate the Device in their own homes with limited researcher oversight.

While standardized approaches to validation exist for tools and instruments used in clinical fields (e.g. receiver operating curves, content / criterion / construct validity) (Portney & Watkins, 2015), these approaches are inappropriate for the Device as it does not provide binary answers, it is not composed of a series of questions, and it does not examine a specific construct. Instead, an engineering approach to validation was appropriate. This approach involved confirming that the most important measures (MT, RT) yielded from the Device were close to or the same as the measures yielded from standard equipment that has been used to measure the Fitts' Task in the past. Validation through this method is achieved with high correlation coefficients and statistical tests related to linear regression between the comparator measures (e.g.

(Scheme & Englehart, 2013). Feasibility was addressed from a ‘Does it work?’ perspective through validation, and from a ‘Will it work?’ perspective through a nominal assessment of the ability of the participants to set up the testing equipment and administer the test to themselves with expert oversight via videochat, emulating how a clinician may oversee a patient testing themselves remotely in a telehealth context (Bowen et al., 2009).

Lacking logistical access to the gold standard equipment, the best method of showing the validity and feasibility of the Device involved replicating a published study and comparing the results of the published study to those yielded by the Device and comparing measurements that produce movement time and reaction time (movement onset and offset) as measured with the accelerometer to movement onset and offset as measured by the touch screen. The study that was chosen to be replicated was Glazebrook et al. (2015): *How one breaks Fitts’s Law and gets away with it: Moving further and faster involves more efficient online control*. This study examined a violation of Fitts’ Law (see section 1.3). There were thus two objectives of the present study: 1) to see if the results of Glazebrook et al. could be replicated; and 2) to examine if the Device was producing statistical outcomes similar to previous studies and results similar to equipment used in the past to measure a Fitts’ Task. It was hypothesized that the Device would yield the same statistical outcomes as the replicated study, and that both the acceleration and touch methods of measuring movement onset and offset would produce the same pattern of results.

Methods

Ethical approval to conduct the present experiment was granted by the University of Manitoba Research Ethics Board. Additional approval was granted to conduct the experiment during the COVID-19 pandemic by the University of Manitoba COVID-19 Research Recovery Team.

Comparator Study

The present study replicated the methods of Glazebrook et al. (2015): *How one breaks Fitts's Law and gets away with it: Moving further and faster involves more efficient online control* ('the comparator study'), except for the measurement devices used. Yielded data was compared to the results of the comparator study. The comparator study used an Optotrak Certus (Northern Digital Inc., Waterloo, Ontario, Canada) set to 300Hz to measure the position of the tip of the dominant index finger throughout the reaching movement via an infrared emitting diode. The primary objective of the comparator study was to determine which kinematic outcome measures were affected by the configuration of Fitts' targets that result in the violation of Fitts Law described in section 1.3. The comparator study was chosen as the study to be replicated because it considered an asymptomatic population that would be easy to reach and recruit in a restricted research environment, it tested a phenomenon that may not be detected by less sensitive equipment or improper data reduction, and the image display procedures could be precisely replicated on the screen of the host computer of the Device.

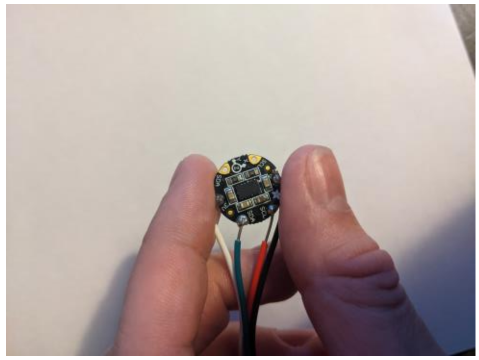
Participants

Participants were recruited from the area including and surrounding Winnipeg, Manitoba, Canada. Inclusion criteria were that participants had to be adults (18+ years of age) who spoke English fluently, were right hand dominant, had normal or corrected-to-normal vision, and were below 35 years of age to avoid any age-induced changes in motor behaviour and to ensure demographics match the comparator study. The exclusion criterion was that no participant had a pathology that may interfere with their motor function, such as recent serious injury, concussion, motor or sensory neurological deficiency. Based on the number of participants tested in the study reported by Glazebrook et al. (2015) and an a-priori power calculation performed with G*Power (Faul et al., 2007) based on the data from that report (relative target location effect size=0.731, α=0.05, β=0.80 | sample size required for significant main effect: N=2), the objective number of participants was chosen to be 20.

Accelerometer/Microcontroller & Software

Three pieces of equipment were used to perform the experiment; the accelerometer, the microcontroller, and the host computer. The accelerometer was the Adafruit FLORA LSM303 (Adafruit, New York City, USA) (Figure 2). It had a 12-bit resolution and was set to use a dynamic range of +/-2g (1g = 9.81m/s^2). Dynamic ranges of +/-4g, +/-8g, and +/-16g were also available. The +/- 2g range was chosen to maximize measurement precision. No movement in an upper limb Fitts' Task should exceed around 1g. In the worst-case scenario, a movement downwards, the accelerometer would only be saturated if the movement exceeded 1g. This was not considered to be an issue as the highest accelerations were expected to be aligned with the primary axis of movement, which was not parallel to gravity for the protocol used in the present experiment.

Figure 2: Adafruit FLORA LSM303 accelerometer



The accelerometer was wired to the microcontroller, an Adafruit FLORA V3 (Adafruit, New York City, USA) (Figures 3 & 4). The accelerometer was sewn to a glove worn by the participant such that the accelerometer was mounted near the tip of the index finger of the participant's right hand (Figure 5). The microcontroller was sewn to the dorsal palm of the glove. This mounting method ensured that the Device was easy to put on and take off and that measured acceleration would occur concomitantly with the pointing movement of interest. The microcontroller was connected to the host computer, a Dell XPS 13 2-in-1 2017 (Dell Technologies, TX, USA) (Figure 6), through a USB 2.0 wired interface set to 19200 baud (bit/s); the maximum speed at which the microcontroller would reliably communicate. The cord attaching the microcontroller to the host computer was secured against the wrist of the participant with a hair tie to prevent the cord from getting in the way of the pointing movement The host computer had a screen size of 29.3cm x 16.5cm (resolution: 1920px x 1080px), an Intel Core i7-7Y75 CPU (base clock: 1.3GHz, boost clock: 1.60GHz), and used the Windows 10 Pro 20H2 operating system. The screen had a refresh rate of 60Hz and a touch sampling rate of 120Hz.

Figure 3: Adafruit FLORA V3 microcontroller

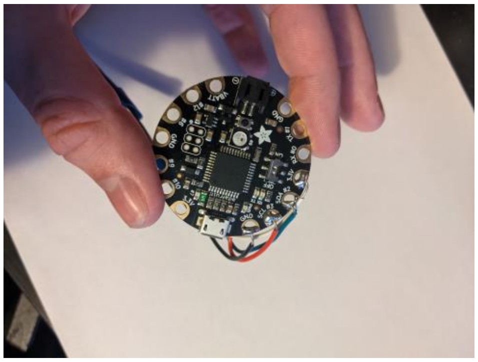


Figure 4: Circuit diagram for microcontroller-accelerometer device

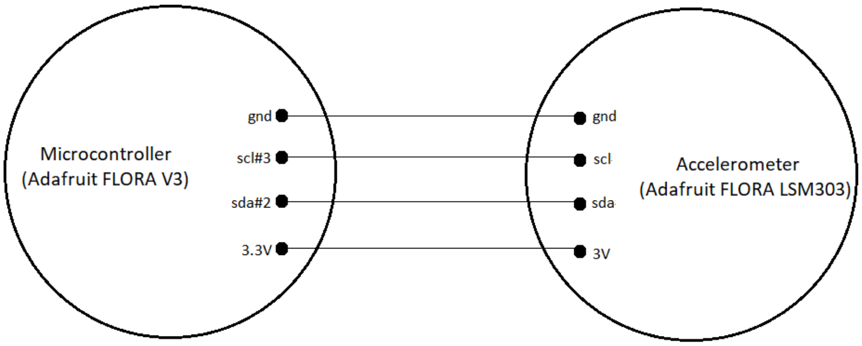


Figure 5: Accelerometer & microcontroller mounted on glove

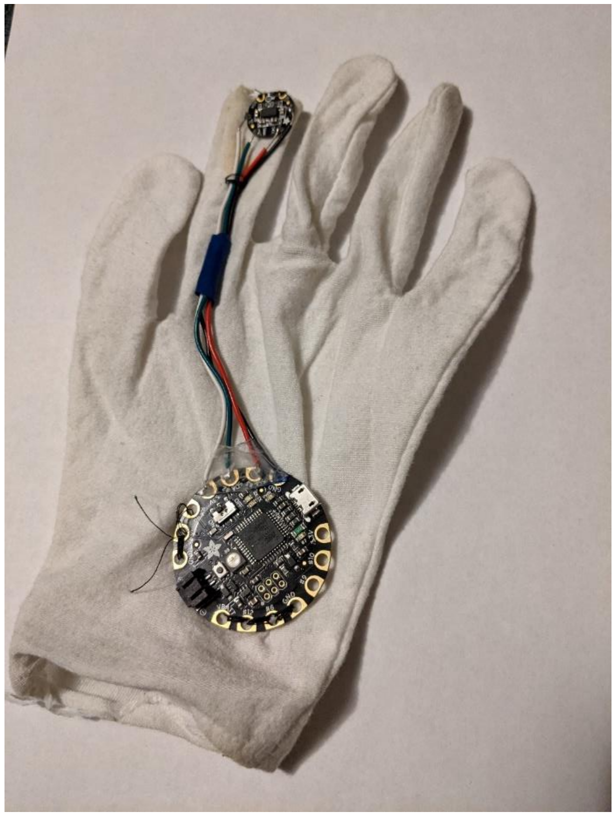
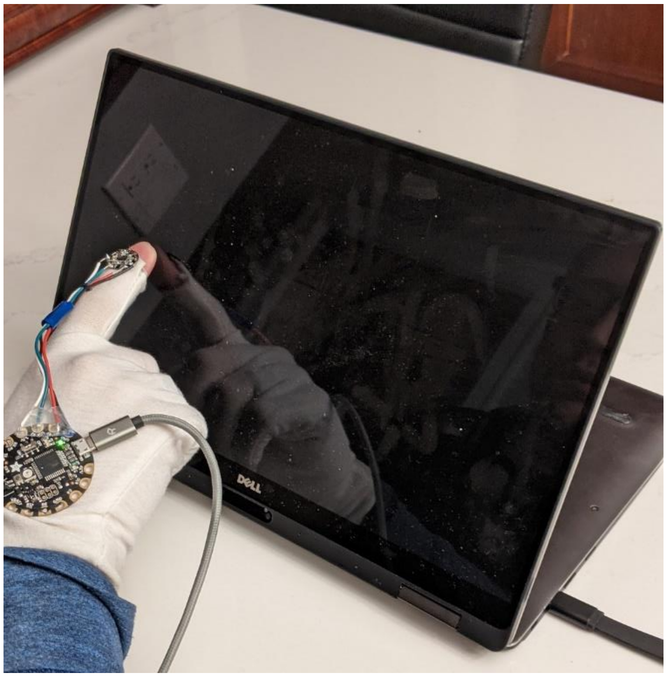


Figure 6: Host computer connected to the Device mounted on a participant



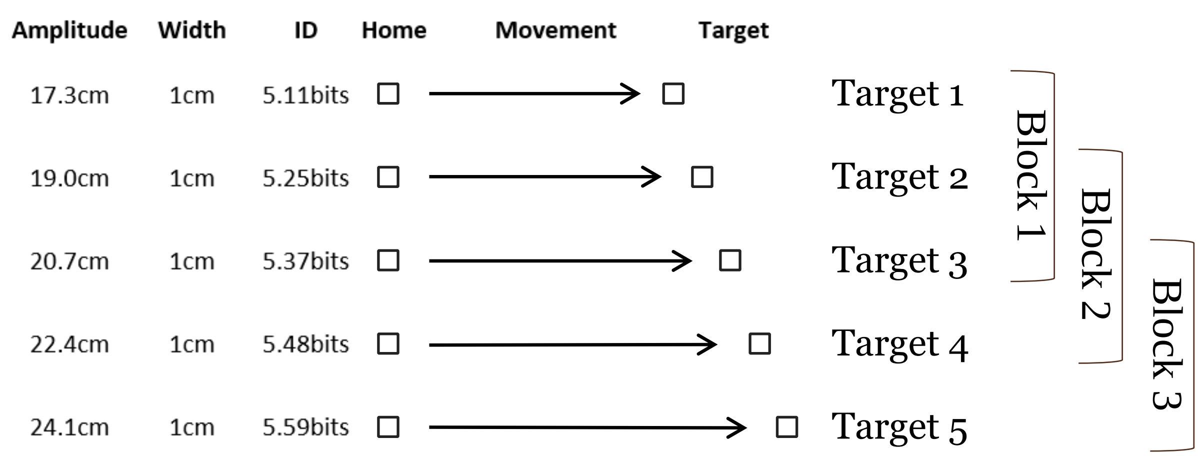
The accelerometer driver (https://github.com/adafruit/Adafruit_LSM303_Accel) was written by Adafruit as open-source software for their LSM303 accelerometers. The microcontroller ran a custom program written in C which facilitated communication between the accelerometer and the host program by responding to a call from the host for a sample, sampling the accelerometer, and sending the sample back to the host. The custom host program, which runs on the host computer, was written in C#. The host program displayed targets, requested accelerometer samples from the accelerometer, and processed accelerometer data to yield outcome measures.

Procedure

The equipment used to conduct this experiment was delivered to participants' places of residence. Participants were overseen via online video communication during the experiment by the experimenter. Through the video chat, the experimenter answered any questions the participant had, guided them through the informed consent process, ensured the equipment was set up properly, and advised the participant on the experimental procedure.

The host computer was placed on a table in front of the participant such that the screen faced the participant and was angled facing up at a 45º angle to the horizontal (Figure 6). The home position was a 1cm square located on the left side of the screen. Five different targets were presented to the right of the home position, all with a width of 1cm and amplitudes of 17.3cm, 19cm, 20.7cm, 22.4cm, and 24.1cm. The targets therefore had ID's of 4.98 bits (Target 1), 5.11 bits (Target 2), 5.23 bits (Target 3), 5.35 bits (Target 4), and 5.45 (Target 5), respectively (Figure 7). Targets were presented in 3 blocks: Block 1, containing targets 1, 2, and 3; Block 2, containing targets 2, 3, and 4; and Block 3, containing targets 3, 4, and 5.

Figure 7: Diagram of the Fitts' Task presented in the present experiment



The present study was concerned with the discrete form of the Fitts' task (see section 1.1). Each trial began with the host program waiting for the participant to touch the displayed home position with their right index finger. This touch caused the program to begin the foreperiod, which was a random length of time between 1.5-2.4s. During this time, baseline acceleration data was collected (‘baseline collection frame’, see section 2.4). During the foreperiod of each trial, all possible targets in that block had their outlines displayed. At the end of the foreperiod, the target chosen for that trial was filled in while the rest remained visible as empty squares on the screen until the end of the trial (Figure 1). Participants were instructed to move ‘as quickly and accurately as possible’ to touch the target once it filled in with their right index finger with a natural unsupported pointing movement (i.e. not by sliding their finger across the screen, but by moving it in a roughly parabolic arc from the home position to the target). They had 2s to make the reaching movement, during which time acceleration data was collected for analysis (the ‘trial collection frame’).

Each target that was included in a block was presented 20 times in each block. Each block consisted of 60 trials, for a total of 180 trials per participant. Trial order and block order were randomized. A series of 10 familiarization trials occurred before the actual trials are presented, which consisted of a random selection of targets 1-5, presented as a block would be (i.e. with placeholder targets displayed during the random foreperiod and reaching movement). Familiarization acclimatized participants to the task before recording began to ensure adherence to trial protocols when recording occurred.

Accelerometer/Microcontroller Data Collection & Processing

Two data collection frames occurred during each trial; one during the variable foreperiod (the ‘baseline sampling frame’), when the accelerometer was polled to collect baseline data, and one during the target presentation (the ‘trial sampling frame’), when the trial data was collected. The baseline sampling frame was the same duration as the foreperiod; a pseudorandom period between 1.5s-2.4s, while the trial sampling frame was 2s for each trial. The sampling rate was set to 250. Hz.

A sampling frequency of 250. Hz should have been sufficient to prevent aliasing of any desirable human movement signal collected during a Fitts' Task. Reaction time (the time between stimulus presentation and the start of motion in response to the stimulus) for an upper limb Fitts' Task is around 300ms and movement time (the time between movement onset and movement offset) is 100ms-500ms (Fitts & Peterson, 1964). Time to peak velocity (ttPV) occurs at ~1/3 into the movement (~33ms-133ms after movement start) (Fowler et al., 2008; Grierson & Elliott, 2009; Passmore et al., 2010, 2014; Passmore, Johnson, et al., 2019; Sargent, 2019) and time to peak acceleration (ttPA) occurs at ~1/4 into the movement (~25ms-125ms after movement start) (Fowler et al., 2008; Grierson & Elliott, 2009; Sargent, 2019). All these measures should have been captured adequately by a sampling rate of 250Hz. According to the Nyquist-Shannon sampling theorem, no aliasing should have occurred (Nyquist frequency = 250Hz / 2 = 125Hz) (Robertson & Dowling, 2003; Shannon, 1998), and all amplitudes should have been captured with reasonable fidelity. As the resolution provided by the accelerometer sampling is 4ms (1s / 250Hz = 4ms), all important events noted above should be distinctly identifiable. Very quick time to peak velocities and accelerations may have caused attenuation of velocity/acceleration peaks, as a common practice is to sample at 10x the rate of the lowest frequency, i.e. 25ms / 10 = 2.5ms (10 x 40Hz = 400Hz), to avoid inaccurate amplitudes.

Two filters were used separately on the acceleration data sets in the present study, with each filtered data set used to derive specific outcome measures. To determine temporal measures derived directly from acceleration data; including movement onset, movement offset, and ttPA; a critically damped filter was used on the raw acceleration data. Between a Butterworth filter and a critically damped filter, a critically damped filter better preserves event characteristics in the time domain (Robertson & Dowling, 2003), and as such temporal measures would have been more accurately identified with a critically damped filter. To determine spatial measures and measures derived from the integrated velocity data, including peak acceleration (PA), peak velocity (PV), and ttPV, a Butterworth filter was used on the raw acceleration data. This was done because a Butterworth filter preserves event characteristics in the frequency domain better, meaning the amplitudes of spatial measures and integrated data will have values closer to true.

A harmonic regression performed using pilot data revealed that the movement data collected during pilot testing had a median frequency of 2.186Hz, mean frequency of 2.727Hz, higher 95th percentile frequency of 5.934Hz, and higher 99th percentile frequency of 17.969Hz. A low pass filter cutoff frequency of 15Hz was chosen as it was between the 95th and 99th percentile frequencies, attenuating high frequency contamination without severely impacting amplitudes. A lowpass filter that is too low may result in wider waveforms (as smaller wavelengths would be filtered out). Therefore, the thresholds associated with movement onset may be reached later than they would be reached without a filter if the threshold is nearer the peak of the wave, or earlier if the threshold is nearer the base of the wave (vice-versa for movement offset). As peak acceleration in the present study hovered around 10m/s^2 and the threshold for movement onset/offset was set to 1.5m/s^2, movement onset may have been estimated to have occurred sooner and movement offset later than when the unfiltered data may have indicated. A high pass filter cutoff frequency of 0.5Hz was chosen as it was determined to mitigate the effects of a poor calibration and/or a baseline with excessive movement causing a small bias when there was no movement occurring. The high pass cutoff frequency was chosen for two reasons. The first reason was that no aspect of the movement should be longer than 2s

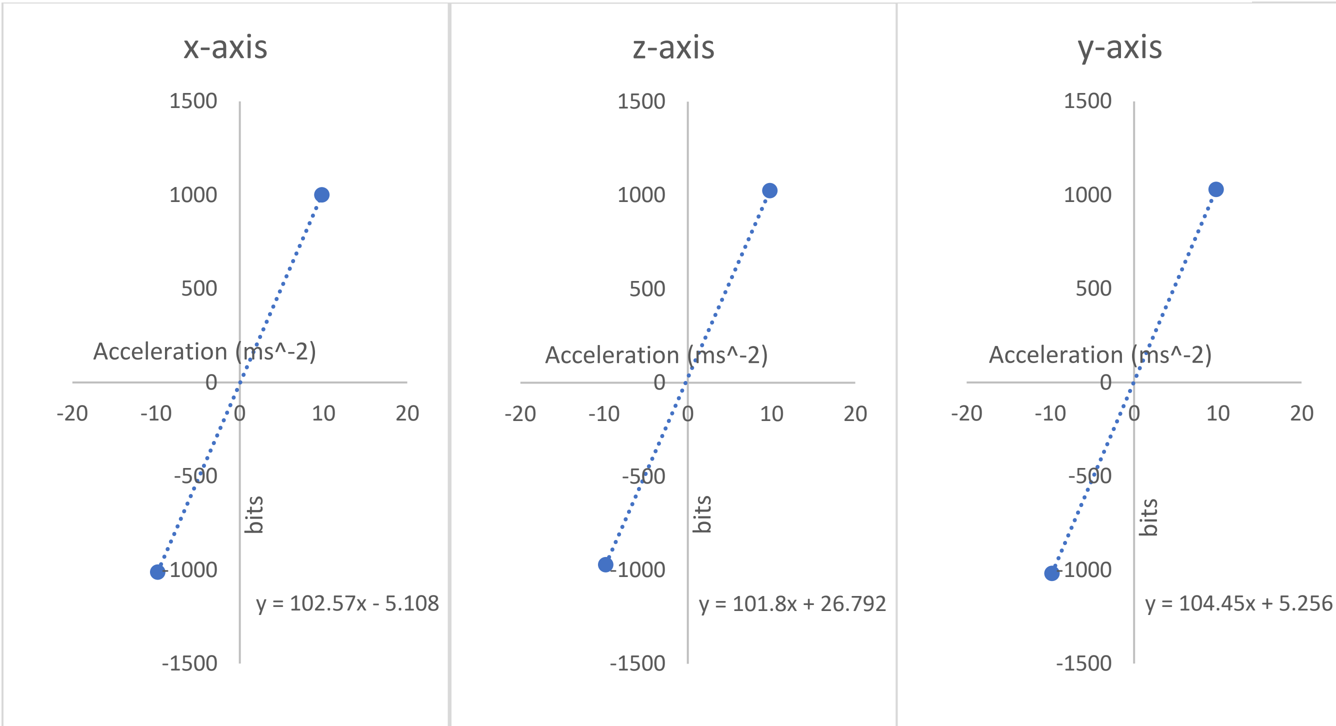
(0.5Hz), as the trial sampling frame was 2 seconds long. The second reason was that low frequencies not native to the sample must be reduced to ensure accurate velocity outcomes because low frequency contamination, such as gravity, causes compounding drift in integrals as time progresses. The drift issue necessitates a somewhat aggressive high pass to ensure accurate PV and ttPV readings. The data was thus filtered using a zero-lag 4th order (2nd order for the low and high pass with one pass in each direction) bandpass filter with reflexive padding of the same length as the sampling frame, with a critically damped filtered data set used to derive movement onset, movement offset, and ttPA; while a Butterworth filtered data set was used to derive PA, PV, and ttPV.

A two-point gravity calibration was performed for each axis. Five seconds of data were collected for each side of the accelerometer, changing which side is facing down for each collection, for a total of 6 data sets. Two data sets were thus collected for each axis, one with the 'positive' side facing up, resulting in a positive bit reading, and one with the 'negative' side facing up, resulting in a negative bit reading. Each data set was averaged, resulting in an average bit reading equivalent to acceleration due to gravity (~9.81m/s^2) with the same sign as the bit reading (Table 1). Linear regression then yielded 3 equations; each associating a given bit reading with an acceleration for each axis (Figure 8).

Table 1: Gravity calibration axis measurements used in the present study

Measurement	1g mean (Raw Bits)
+x	1001
+y	1030.
+z	1025
-x	-1011
-y	-1019
-z	-972

Figure 8: Calibration regression lines and calibration equations used in the present study



A baseline was collected during each trial during the variable foreperiod, lasting the same amount of time as each foreperiod (a pseudorandom time between 1.5s-2.4s). The participant was instructed to remain still during this time, and so each axis was averaged to determine the 'at rest' reading. These values were then subtracted from each point in the appropriate axis in the subsequent trial collection frame to yield an absolute acceleration reading. Application of the filters followed this gravity subtraction step.

Outcome Measures & Data Reduction

Glazebrook et al. (2015) reported reaction time (RT), movement time (MT), constant error (CE), variable error (VE), and peak velocity (PV). The present report does the same, with the addition of reporting time to peak velocity (ttPV), peak acceleration (PA), and time to peak acceleration (ttPA). The outlier rejection methods and statistical models were also replicated. A trial was rejected if RT or MT exceeded ±2.5 times the standard deviation from the mean performance of that participant to the target to which they aimed. Additionally, any trial that had a calculated RT or MT <100ms was rejected, as neither of these values should be possible without anticipation or movement errors, respectively (Plamondon & Alimi, 1997). Trials in which the movement endpoint was >1cm from the center of the target (trials in which targets were missed) were also rejected.

All outcome variables were calculated for each target in each block independently. For the determination of movement onset and movement offset, the total resultant acceleration was calculated. As two measurement techniques were used (touch and acceleration), many outcome measures were derived twice, once for each measurement method. Movement onset was defined in two different ways; as the first time in the trial collection frame when three consecutive resultant acceleration samples exceeded $1.5 m/s^2$, and as when the participant lifted their finger from the touchscreen. Movement offset was also defined in two ways; first as the first point after movement start where 200ms had passed where no three consecutive samples exceeded $1.5 m/s^2$, and second as when the participant first contacted the touchscreen after movement start. Reaction time was defined as the difference in time between target presentation and movement onset, while MT was the difference in time between movement onset and movement offset. Both the acceleration method and the touch method of movement determination were used to generate RT and MT values, which separately underwent statistical analysis in the same fashion as other variables (see section 2.7), and comparison with the comparator study outcomes. Each acceleration axis was integrated to yield velocity for that axis. Peak acceleration and PV were the peak resultant values during the movement for the appropriate data set, while ttPV and ttPA were the time at which the peak resultant value was collected compared to movement onset as determined by either the acceleration or touch method. Movement endpoint (i.e. the place on the host screen that was struck at the end of the movement) was measured by the host computer touchscreen. Constant error was the mean distance from the centre of the presented target to the movement endpoint along the x-axis (horizontal axis) of the host computer screen, and VE was the standard deviation of the movement endpoint along the x-axis.

Statistical Models

All variables collected in the present study were tested in the same way as the comparator study. The level of significance was set to $\alpha=0.05$. There were 2 groups of statistical tests used on all measured variables: a 2-way, 3 Block (Block 1, Block 2, Block 3) x 3 Relative position (nearest, middle, farthest) repeated measures ANOVA on all targets; and a 1-way, 3 relative position (nearest, middle, farthest) repeated measures ANOVA on only trials with Target 3 as the objective target. The tests on only Target 3 isolated the effects of position in an array on MT as Target 3 was the only target that appeared at all 3 array positions (nearest, middle, farthest). The movement analysis performed in the comparator study was not conducted, as displacement measurements during the movement are unreliable when derived from an accelerometer. Tukey's Honestly Significant Difference (Tukey's HSD) was used to determine the locus of any significant differences identified in the ANOVAs. Planned paired sample t-tests were also performed between the middle and far Target 3 positions to catch the smallest possible significant differences between middle and far positions for MT and PV. Categorical comparisons were then made between the statistical outcomes of the present study and the outcomes in the comparator study to determine if the present study produced the same conclusions as the comparator study.

To validate the acceleration-based method of measuring movement onset and movement offset, correlations were performed between the touch- and acceleration-based measurements of movement onset and movement offset for all valid trials from all participants. Touchscreens have been used in the past to measure a Fitts' Task (Adam et al., 2006; Pratt et al., 2007), so this comparison between methods is a reasonable validation method. Movement onset and offset were chosen as the comparator measures for validation because these variables are directly extracted from yielded data sets and the most important measures for a Fitts' Task, MT and RT, are derived from these values.

Excel (Microsoft, Redmond, USA, 2018) was used to reduce data when the host program did not derive a specific variable. The program jamovi v.1.2 (The jamovi project, 2021) was used to calculate statistical outcomes.

Results

Twenty-two participants were recruited (N: 22; gender identity: 11 female, 11 male; age: 25.5±1.8years).

Tests for Fitts' Law

Outcome measures for acceleration-derived variables are listed in Table 2 and touch-derived variables in Table 3. No significant differences were found for the ANOVAs concerning just the relative position of Target 3, so the results of these tests are not discussed below. In total, 8.8% of trials were rejected (mean: 15.8 trials/participant, median: 11 trials/participant).

Table 2: Acceleration-derived outcome measures by block and target

Block	Target	MT (ms)	RT (ms)	PA (m/s^2)	ttPA (ms)	PV (m/s)	ttPV (ms)
Block 1	Target 1	463 ± 62	254 ± 34	9.69 ± 3.09	125 ± 65	0.814 ± 0.233	179 ± 21
	Target 2	483 ± 66	253 ± 34	10.4 ± 3.50	132 ± 60	0.906 ± 0.257	186 ± 25
	Target 3	500 ± 73	254 ± 27	10.8 ± 3.73	167 ± 61	0.996 ± 0.290	191 ± 22
Block 2	Target 2	490 ± 78	257 ± 31	10.3 ± 2.79	146 ± 66	0.892 ± 0.220	183 ± 21
	Target 3	514 ± 81	249 ± 45	10.5 ± 3.11	167 ± 70	0.979 ± 0.234	196 ± 25
	Target 4	517 ± 77	252 ± 47	11.3 ± 3.46	178 ± 75	1.06 ± 0.253	200 ± 28
Block 3	Target 3	500 ± 87	260 ± 28	10.8 ± 3.81	173 ± 78	0.972 ± 0.269	196 ± 28
	Target 4	519 ± 84	254 ± 30	11.1 ± 3.86	167 ± 66	1.05 ± 0.275	201 ± 27
	Target 5	536 ± 79	259 ± 32	11.9 ± 4.28	185 ± 57	1.15 ± 0.283	204 ± 27

Values are presented as mean ± standard deviation

Table 3: Touch-derived outcome measures by block and target

Block	Target	MT (ms)	RT (ms)	ttPA (ms)	ttPV (ms)	CE (mm)	VE (mm)
Block 1	Target 1	436 ± 126	307 ± 30	72.6 ± 63	127 ± 29	2.59 ± 1.09	2.81 ± 1.06
	Target 2	447 ± 132	307 ± 30	77.5 ± 57	132 ± 33	2.30 ± 1.59	2.67 ± 0.997
	Target 3	450 ± 128	311 ± 23	110 ± 56	134 ± 32	2.20 ± 1.43	2.77 ± 0.907
Block 2	Target 2	445 ± 116	311 ± 31	92.1 ± 65	129 ± 27	2.30 ± 1.45	2.89 ± 0.932
	Target 3	468 ± 118	306 ± 37	110 ± 61	139 ± 29	2.35 ± 1.30	2.47 ± 0.873
	Target 4	465 ± 115	308 ± 35	121 ± 67	144 ± 33	2.59 ± 1.22	2.73 ± 0.848
Block 3	Target 3	468 ± 135	314 ± 26	119 ± 76	142 ± 32	2.33 ± 1.41	2.69 ± 1.12
	Target 4	484 ± 134	307 ± 31	114 ± 65	148 ± 31	2.21 ± 1.23	2.64 ± 0.961
	Target 5	497 ± 142	313 ± 30	131 ± 56	150 ± 35	2.66 ± 1.57	2.86 ± 1.14

Values are presented as mean ± standard deviation

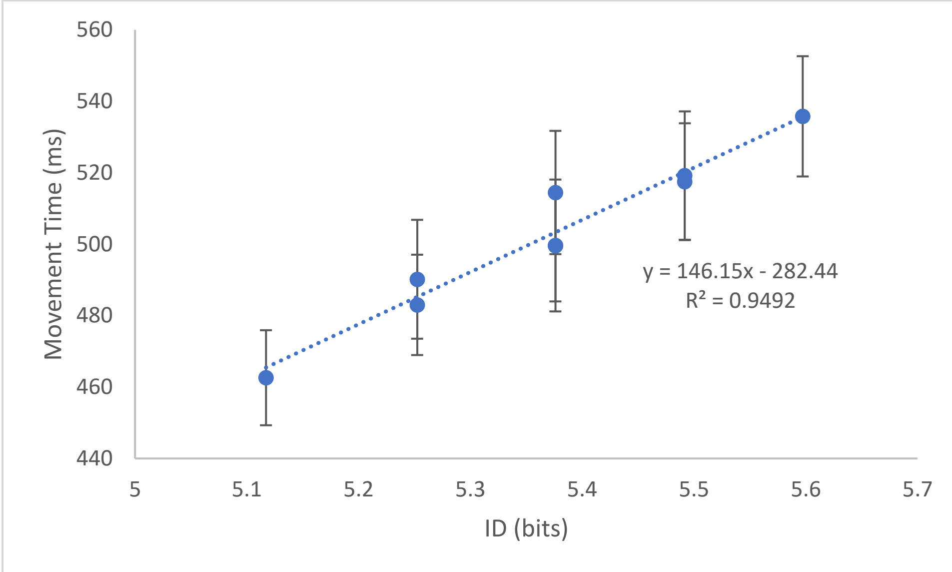
Movement Time

The block x relative position ANOVA performed on MT values derived from acceleration data yielded significant effects for block ($F_{2,42}$=14.85, η^2_p=0.414, p<0.001) and relative position ($F_{2,42}$=53.29, η^2_p=0.717, p<0.001) (Figures 9 & 10). The post-hoc tests revealed that Block 1 had a significantly shorter MT than blocks 2 or 3. Additionally, the nearest target had a significantly shorter MT than the middle or farthest target and the middle target had a significantly shorter MT than the farthest target.

Significant differences were also revealed when MT derived from the touch data was analyzed. Tests for block ($F_{2,42}$=9.48, η^2_p=0.311, p<0.001), relative position ($F_{2,42}$=38.50, η^2_p=0.647, p<0.001), and block x relative position ($F_{4,84}$=2.65, η^2_p=0.112, p=0.039) showed significant differences (Figures 11 & 12). Movement time to Block 3 was found to be significantly longer than MT to blocks 1 or 2, and MT to the nearest target was shown to be significantly shorter than to the middle or farthest targets. Notably, MT to the middle and farthest targets were not significantly different. For the interaction, MT to targets in block 1 were not significantly different from each other, while in blocks 2 and 3, MT to the nearest target was found to be significantly shorter than the middle or farthest target while the middle and farthest target were not significantly different.

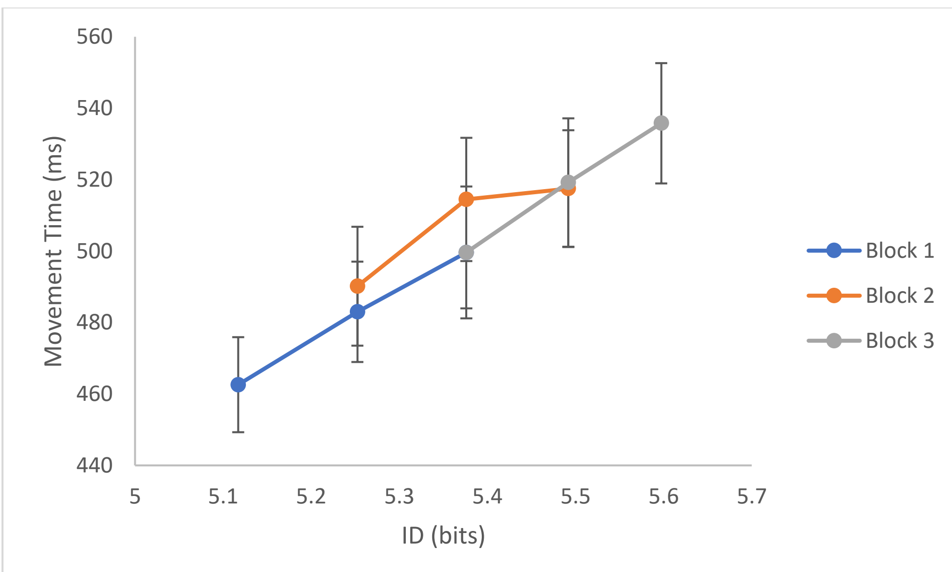
The t-tests comparing MT to target 3 in the middle and farthest array position revealed that MT to target 3 in the middle array position was significantly longer than to target 3 in the farthest array position for both acceleration (t_{21}=2.29, p=0.032) (Figure 13) and touch (t_{21}=2.15, p=0.043) (Figure 14).

Figure 9: Linear regression of acceleration-derived movement time by ID



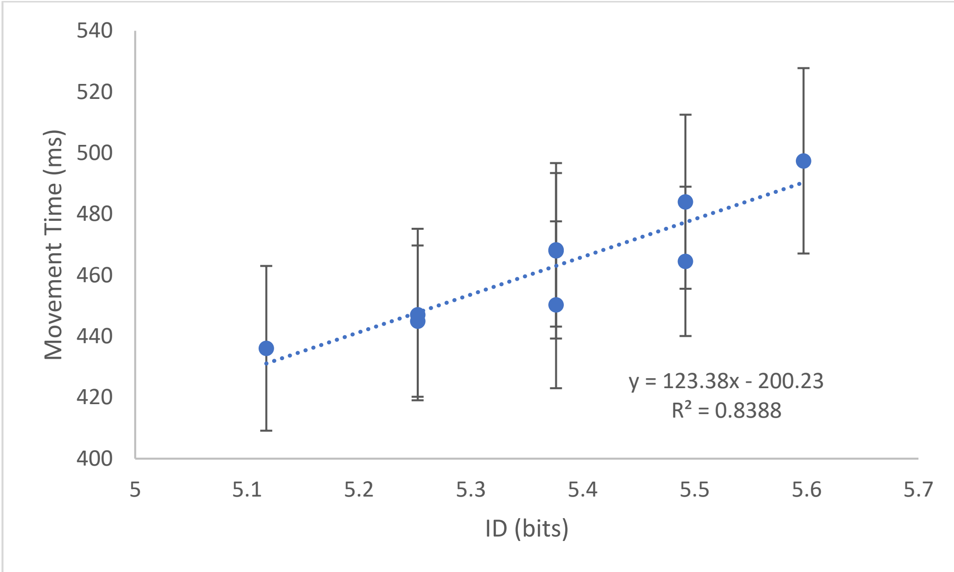
Error bars represent standard error.

Figure 10: Acceleration-derived movement time by ID grouped by block



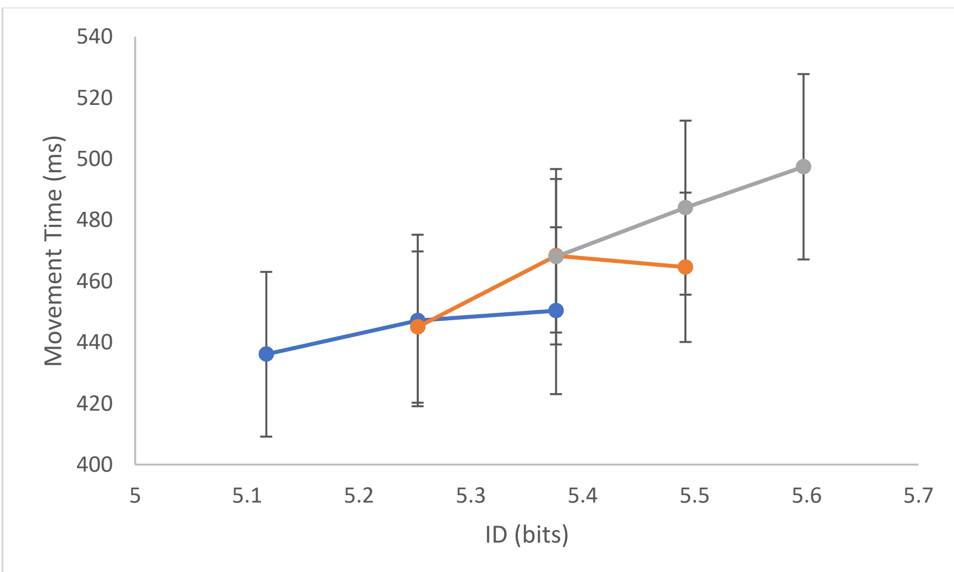
Error bars represent standard error.

Figure 11: Linear regression of touch-derived movement time by ID



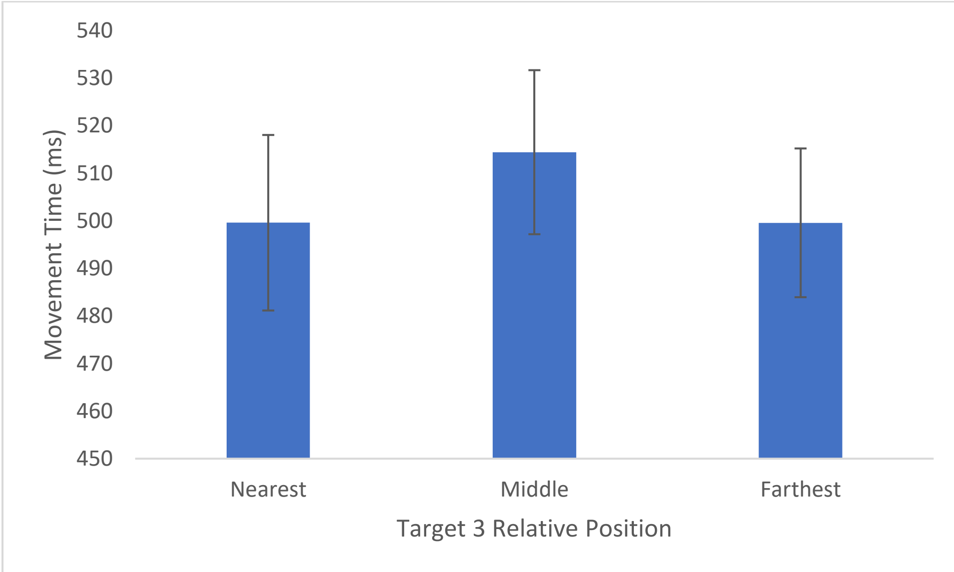
Error bars represent standard error.

Figure 12: Touch-derived movement time by ID grouped by block



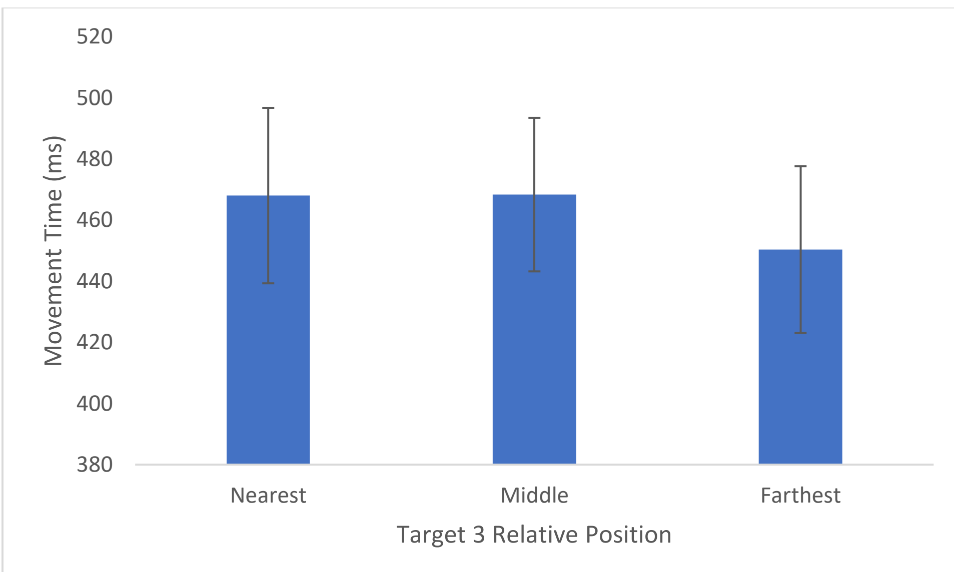
Error bars represent standard error.

Figure 13: Acceleration-derived movement time to Target 3 in various relative array positions



Error bars represent standard error.

Figure 14: Touch-derived movement time to Target 3 in various relative array positions



Error bars represent standard error.

Reaction Time

Consistent with previous investigations of this violation of Fitts' Law (and most investigations of Fitts' Law in general), there were no significant differences for RT between any of the investigated conditions in any statistical test run in the present study.

Peak Velocity

The block x relative position ANOVA analyzing PV revealed a significant effect for block ($F_{2,42}$=15.22, η^2_p=0.420, p<0.001) and relative position ($F_{2,42}$=177.34, η^2_p=0.894, p<0.001). The post-hoc analyses revealed that block 1 < block 2 < block 3 and that nearest < middle < farthest.

The t-test comparing target 3 at the middle and farthest positions revealed no significant difference for PV.

Peak Acceleration

Significant effects for peak acceleration were found for both block ($F_{2,42}$=3.95, η^2_p=0.158, p=0.027) and relative position ($F_{2,42}$=24.47, η^2_p=0.538, p<0.001). The post-hoc tests revealed that block 1 < block 3 and that nearest < middle < farthest.

Time to Peak Velocity

Comparisons of ttPV found significant effects for block ($F_{2,42}$=12.38, η^2_p=0.371, p<0.001), relative position ($F_{2,42}$=30.15, η^2_p=0.589, p<0.001), and block x relative position ($F_{4,84}$=3.34, η^2_p=0.137, p=0.014) when the ttPV was derived from movement onset derived from acceleration data. Post-hoc tests revealed that ttPV for block 1<block 2<block 3 and nearest<middle<farthest. Tests for the interaction between block and relative position reveled

that unlike in blocks 1 & 3, where the near target was not significantly different from the middle target, ttPV to the nearest target in block 2 was significantly shorter than to the middle target.

The tests of ttPV as derived from the point at which touch data determined movement onset revealed a similar pattern, with significant effects for block ($F_{2,42}$=12.80, η^2_p=0.379, $p<0.001$) and relative position ($F_{2,42}$=23.90, η^2_p=0.532, $p<0.001$), but not for block x relative position. Tuckey's HSD showed that block 1 and block 2 were lower than block 3, and that ttPV to the nearest target was shorter than middle or farthest. Notably, the difference in ttPV to the middle and farthest targets were not significantly different.

Time to Peak Acceleration

For ttPA from acceleration movement onset, significant effects were found for block ($F_{2,42}$=8.31, η^2_p=0.283, $p<0.001$) and relative position ($F_{2,42}$=16.87, η^2_p=0.445, $p<0.001$). Further testing showed that ttPA in block 1 was shorter than in blocks 2 or 3 and that ttPA to the farthest target in an array was longer than to the nearest or middle targets, while ttPA to the middle and nearest targets were not significantly different.

For ttPA from touch movement onset, significant effects were also found for block ($F_{2,42}$=8.72, η^2_p=0.293, $p<0.001$) and relative position ($F_{2,42}$=14.04, η^2_p=0.401, $p<0.001$). Post-hoc testing revealed the same pattern of results as was found for ttPA from acceleration movement onset.

Constant Error

No significant effects were found for constant error.

Variable Error

No significant differences were found for constant error with the pre-planned tests, though there was a trend approaching significance for relative position ($F_{2,42}$=2.685, η^2_p=0.113, p=0.08).

Target Misses

No significant differences were found for any test run on the number of target misses.

Comparisons with Glazebrook et al (2015)

As can be seen in Table 4, the results of the block x relative position comparisons on data from acceleration values in the present study and the comparator study (Glazebrook et al., 2015) are the same for the most important variables (MT, RT), and show similar patterns for other variables. Some differences do exist in the post-hoc test results; importantly, Glazebrook et al. found that there was no significant difference between the MTs to the middle and farthest conditions in the block x relative position ANOVA, while the acceleration derived values from the present study revealed that reaching to the middle target resulted in a significantly shorter MT. Similar statistical test results were also gained from both the Target 3 relative position tests (no differences for all 3 data collection methods) and the pre-planned t-tests.

Table 4: Block x Relative position ANOVA p-values from tests on results gained from acceleration, touch, and the comparator study

	Acceleration	Touch	Comparator
		MT	
Block	< 0.001*	< .001*	<0.01*
Relative Position	< 0.001*	< .001*	<0.001*
Block ✻ Relative Position	>0.05	<0.05*	>0.05

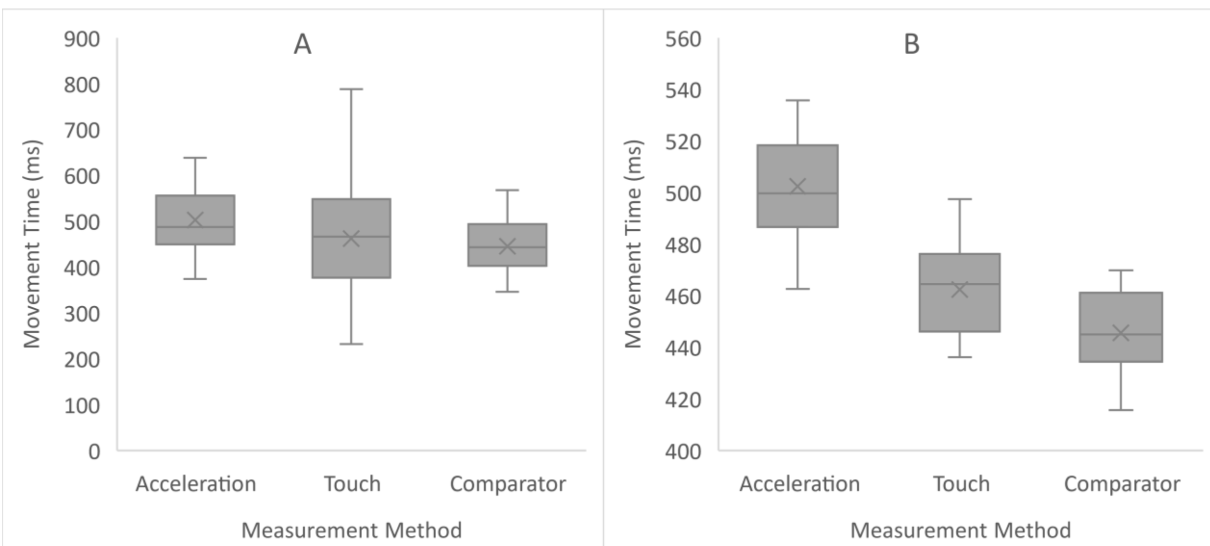
		RT	
Block	>0.05	>0.05	>0.05
Relative Position	>0.05	>0.05	>0.05
Block ✻ Relative Position	>0.05	>0.05	>0.05
		ttPA†	
Block	< 0.001*	< .001*	>0.05
Relative Position	< 0.001*	< .001*	<0.01*
Block ✻ Relative Position	>0.05	>0.05	>0.05
		ttPV†	
Block	< 0.001*	< .001*	<0.05*
Relative Position	< 0.001*	< .001*	<0.001*
Block ✻ Relative Position	<0.05*	>0.05	>0.05
		Peak Vel	
Block	< 0.001*	N/A	<0.001*
Relative Position	< 0.001*	N/A	<0.001*
Block ✻ Relative Position	>0.05	N/A	>0.05
		Peak Accel†	
Block	<0.05*	N/A	>0.05
Relative Position	< 0.001*	N/A	>0.05
Block ✻ Relative Position	>0.05	N/A	>0.05
		Constant Error	
Block	N/A	>0.05	<0.001*
Relative Position	N/A	>0.05	<0.001*
Block ✻ Relative Position	N/A	>0.05	>0.05
		Variable Error	
Block	N/A	>0.05	>0.05
Relative Position	N/A	>0.05	>0.05
Block ✻ Relative Position	N/A	>0.05	<0.05*
		Target Misses	
Block	N/A	>0.05	>0.05
Relative Position	N/A	>0.05	<0.05*
Block ✻ Relative Position	N/A	>0.05	<0.001*

*A result of significantly different within that data set.

†Data used in for Glazebrook et al. (2015) was used to generate these test results, but these results were not reported in the original article.

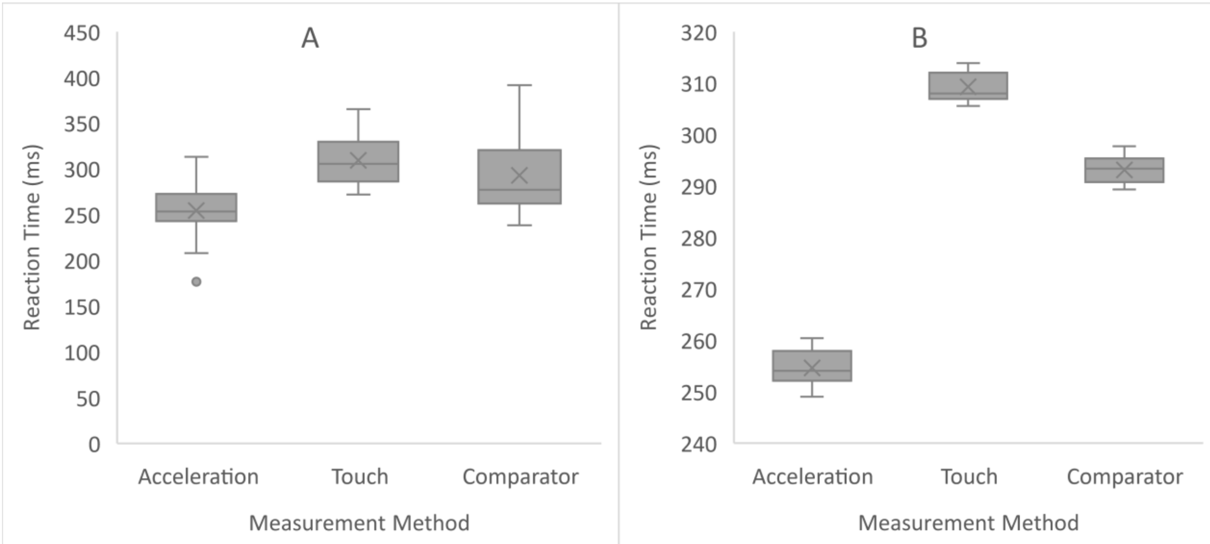
Most measures were similar between the three different methods (i.e., between acceleration, touch, and the outcome measures from Glazebrook et al, 2015) (Figures 15-21). All ranges from any measurement method are within the same order of magnitude as the other examined measurement methods.

Figure 15: Ranges of movement time measurements from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



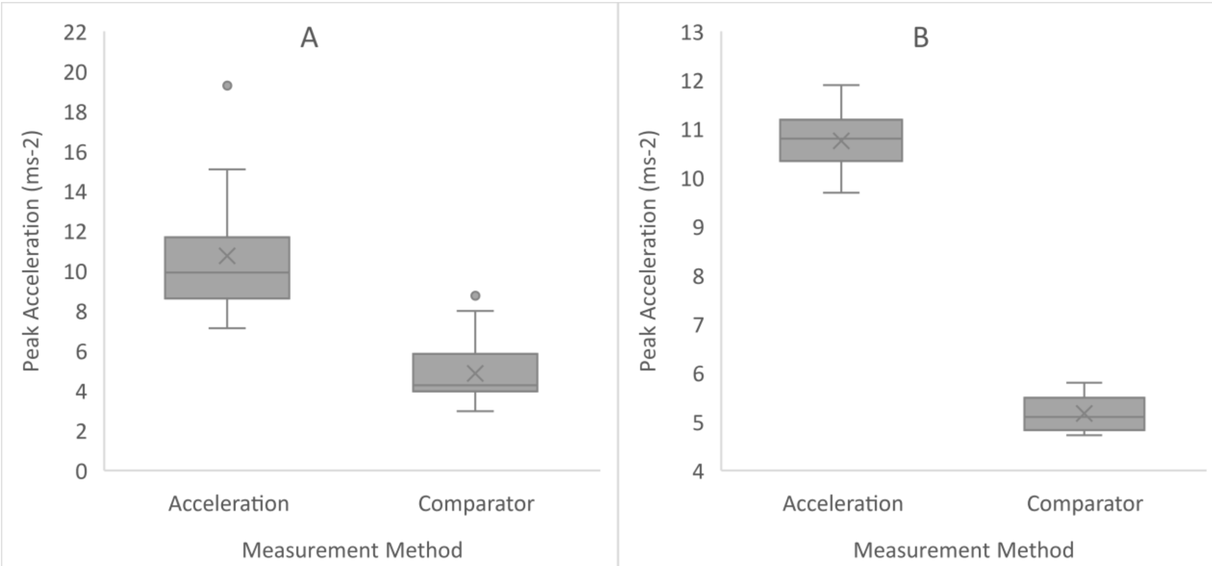
Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average movement time value for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average movement time values for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The ‘x’ represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Figure 16: Ranges of reaction time measurements from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



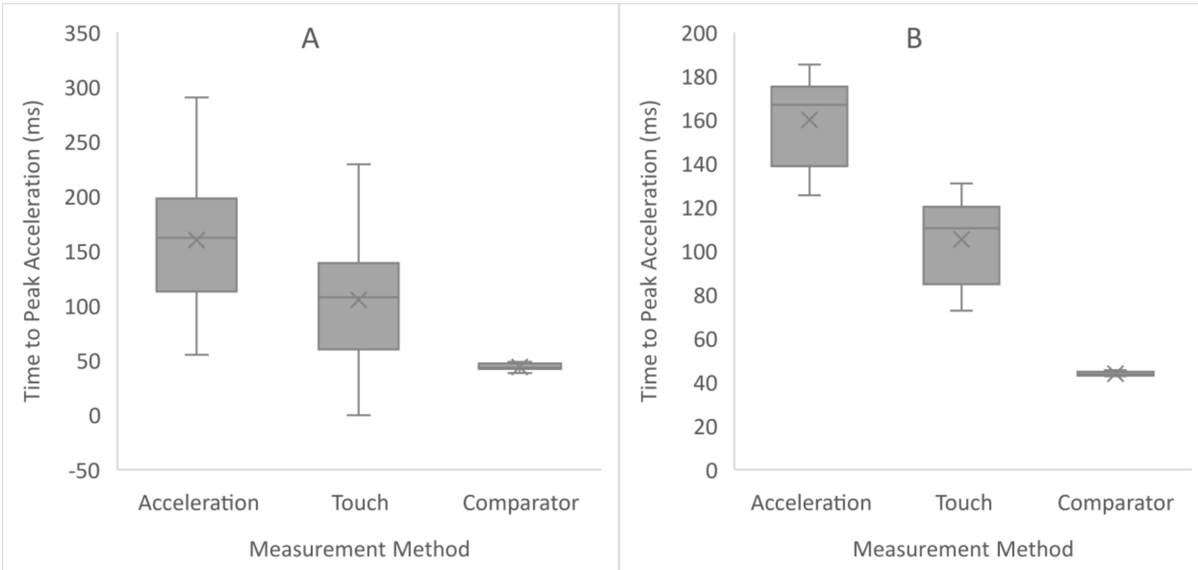
Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average reaction time value for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average reaction time values for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The ‘x’ represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Figure 17: Ranges of peak acceleration measurements from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



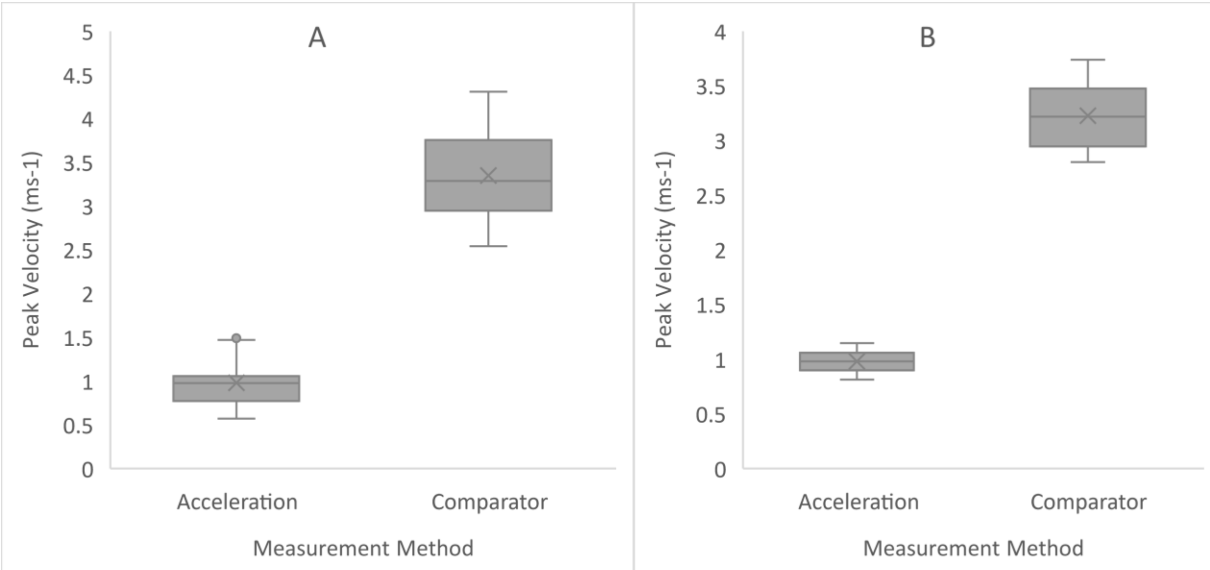
Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average peak acceleration value for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average peak acceleration values for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The ‘x’ represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Figure 18: Ranges of time to peak acceleration measurements from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



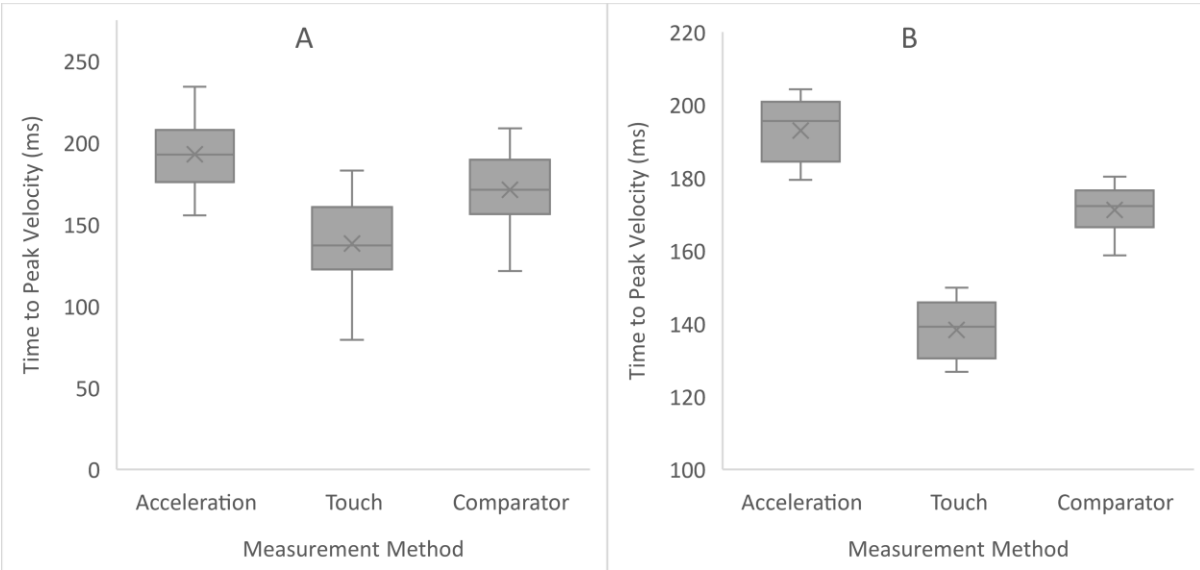
Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average time to peak acceleration value for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average time to peak acceleration values for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The ‘x’ represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Figure 19: Ranges of peak velocity measurements from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



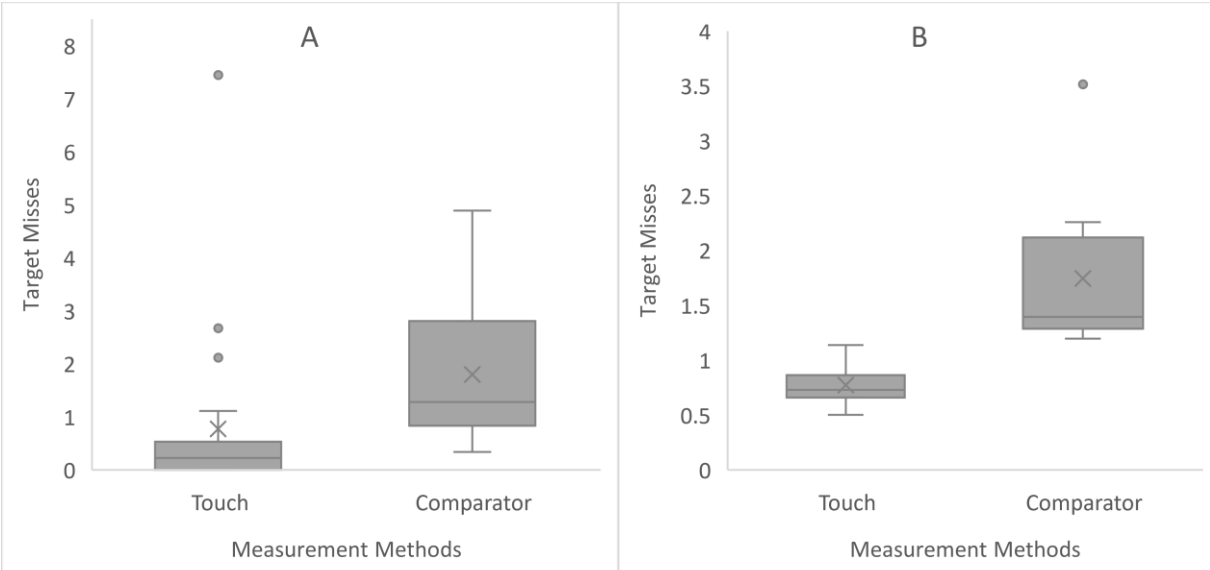
Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average peak velocity value for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average peak velocity values for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The ‘x’ represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Figure 20: Ranges of time to peak velocity measurements from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average time to peak velocity value for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average time to peak velocity values for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The 'x' represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Figure 21: Ranges of target misses from acceleration, touch, and Glazebrook et al. (2015) datasets by overall participant averages (A) and by overall target averages (B)



Comparator refers to the measurements that formed the basis for the report by Glazebrook et al. (2015). Graph A was generated by averaging all values generated by each participant, creating an average number of target misses for each participant (N=22, 22, and 18, respectively), all of which were then graphed. Graph B was generated by averaging all values generated by all participants for each target in each array (9 target/array pairs), creating average number of target misses for each target/array combination, which were then graphed. Note: Dots represent outliers which are >1.5x the interquartile range from the mean. The 'x' represents the mean, while the horizonal bar within the box represents the median. Whiskers extend to the minimum and maximum values unless outliers exist, in which case they extend to 1.5x the interquartile range.

Comparisons between Touch and Acceleration Data

The linear regressions run on the movement onsets and offsets derived from touch and acceleration data revealed significant correlations for both movement onsets (t=240.4, p<0.001) (Table 5, Figure 15) and movement offsets (t=72.1, p<0.001) (Table 6, Figure 16). The line of best fit for movement onset is;

$$M_{On\ accel} = 0.975M_{On\ touch} - 45.262ms \qquad \textit{Equation 3}$$

where $M_{On\ accel}$ is movement onset as determined by acceleration data and $M_{On\ touch}$ is movement onset as determined by touch data.

The line of best fit for movement offset is;

$$M_{Off\ accel} = 0.643M_{Off\ touch} + 261.813ms \qquad \textit{Equation 4}$$

where $M_{Off\ accel}$ is movement offset as determined by acceleration data and $M_{Off\ touch}$ is movement offset as determined by touch data.

Table 5: Statistical results of linear regression of movement onset as determined by touch vs. acceleration

Predictor	Estimate	SE	t	p
Intercept	-45.262	1.30060	-34.8	< .001
Touch Movement Onset	0.975	0.00406	240.4	< .001

Figure 22: Linear regression of movement onset as determined by touch and acceleration

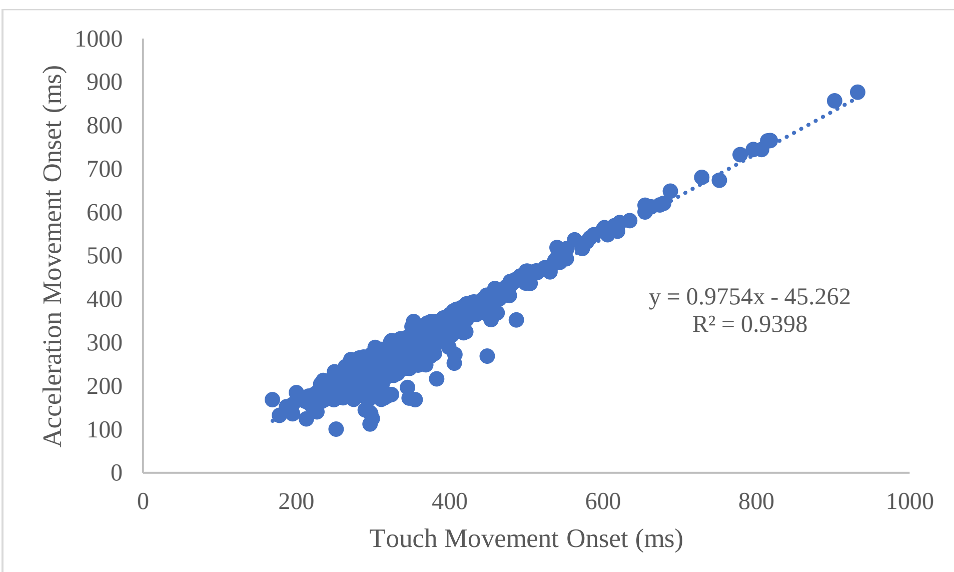
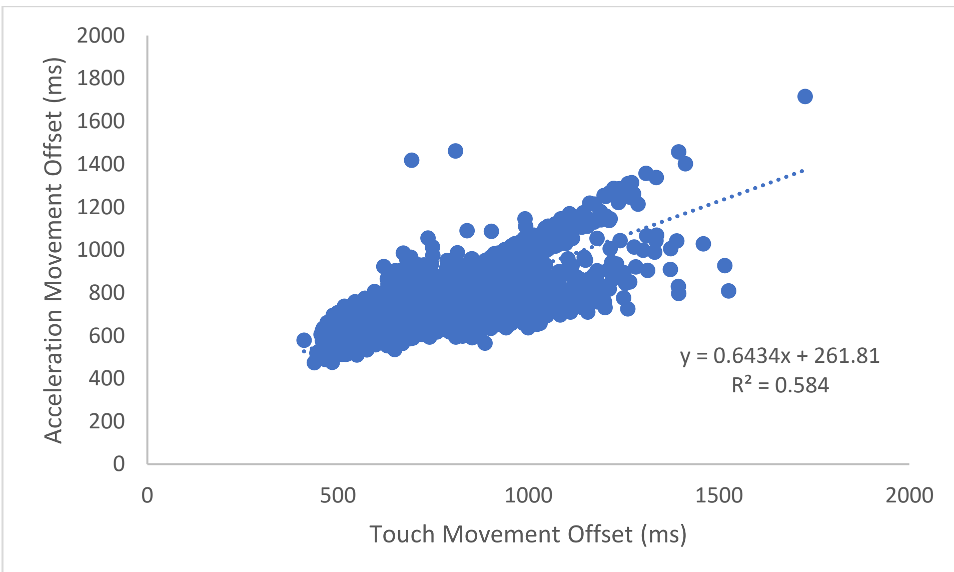


Table 6: Statistical results of linear regression of movement offset as determined by touch vs. acceleration

Predictor	Estimate	SE	t	p
Intercept	261.813	7.13613	36.7	< .001
Touch Movement Offset	0.643	0.00892	72.1	< .001

Figure 23: Linear regression of movement offset as determined by touch and acceleration data



Discussion

Review of Objectives

The objectives of the present study were twofold; 1) to replicate the results of Glazebrook et al. (2015) using the same target presentation methods, and 2) to examine the validity and feasibility of the Device. Glazebrook et al. (2015) demonstrated a ‘violation’ of Fitts’ Law involving borders surrounding possible targets, called placeholder targets, being present before and during target presentation (Figure 1). This configuration results in no significant difference for MT to the middle and far targets in a given array. The present study used the Device, which consisted of an accelerometer/microcontroller sewn onto a glove and a series of programs that display targets, sample the accelerometer, store, reduce, and extract outcome measures.

Was Fitts' Law Violated?

The results of the present study are broadly the same as Glazebrook et al. (2015). While the details of some of the post hoc tests are different, the results of the omnibus ANOVAs for the accelerometer data outcomes and the comparator study are the same for all crucial tests conducted (Table 4). The most critical test outcomes are those for MT. The difference in results between the acceleration and touch data are discussed in depth in section 4.3. The t-test that Glazebrook et al. (2015) conducted to give the most liberal interpretation of differences between the three possible Target 3 positions yielded the same results in the present study, with the far position resulting in significantly shorter MT than movements to the middle position for both the touch and acceleration derivations. Previous studies have provided evidence of the violation (Adam et al., 2006; Blinch et al., 2012; Bradi et al., 2009; Pratt et al., 2007; Radulescu et al., 2010; Roberts et al., 2016), including Glazebrook et al. (2015). These studies used similar methods and yielded similar results as the present study. The violation of Fitts' Law is thus supported by the present study.

Explanations put forward in the past concerning the causes for the violation of Fitts' Law examined in the present study have focused on the hypothesis that the target array generated by the placeholder targets are organized as a gestalt in the mind of the viewer. The gestalt hypothesis alleges that when a performer is asked to move towards the edge of an array, they are able to move more quickly than they would be able to without the placeholder targets present. Faster movement to edge targets in an array has been thought to be accomplished either through more efficient motor planning or through more efficient online control processes (Blinch et al., 2012; Glazebrook et al., 2015; Roberts et al., 2016). These two perspectives, the planning hypothesis and the online control hypothesis, have been the cause for many of the studies considering the violation. Both explanations are likely true, as it has been found that the violation does not occur if placeholder targets are absent during the movement preparation stage and that the locus of the violation exists within the secondary movements. Thus, the cause of the violation comes from both the preparation and execution of the movement. Descriptions of *why* such differences exist when placeholder targets are present have focused on the centre of the gestalt creating a 'repulsion effect.' These descriptions have tended to emphasize that performers move to the far target faster than to the middle target(s). Adam et al. (2006) theorized that placeholders compete for attention during the pointing task, creating an allocentric repulsor. This alleged effect has been thought to cause a disruption in the primarily egocentric Fitts' Task and thus cause a violation. While this description may be accurate, no previous study has focused on why attention is focused on the target placeholders, and have instead focused solely on the differences in MT to the middle and far target. While the description Adam et al. (2006) put forward is intriguing, it is insufficient to be used as a tool for knowledge translation and does not explain why attention is given to the target placeholders or why a repulsion effect exists. It is more a description of what occurs rather than a reason for why the violation happens. An explanation that fills these gaps is that performers tend to try and avoid placeholder targets because they do not want to accidentally hit them.

When aiming to a target without flanking placeholders (i.e. a standard Fitts' Task), participants are inclined to be comfortable with a certain amount of error, as long as they land near the target. When a placeholder target flanks the objective target on only one side, the performer is inclined to aim towards the side of the target flanked by a void, as a placeholder target that may be perceived to be an 'incorrect' response is not present on the side of the void. When the objective target is flanked on both sides along the primary axis of movement by placeholder targets, performers prioritize accuracy higher than they would to a target without a flanking placeholder because they feel an impulse to avoid either of the flanking target placeholders. When a zone that incurs a penalty exists, performers optimize their movements to account for the inherent variability of the human motor system, and so aim far enough away from those zones to not risk hitting them (Gallivan et al., 2018; Gepshtein et al., 2007; Trommershäuser et al., 2003). A neutral zone, such as an area filled with neither a target placeholder or the objective target, is seen as non-optimal, but is a preferable zone to hit in error compared to a zone with a perceived negative consequence (Trommershäuser et al., 2003). Even in a situation without explicit consequences for missing, such as in the task examined in the present report, performers may be inclined to avoid obstacles they have learned have consequences (LeBlanc et al., 2020), such as target placeholders. An anecdotal but practical example of the inclination to over-prioritize accuracy to the middle target is pointing to app icons on a touchscreen. When the desired app (the objective target) is not surrounded by other app icons, the consequences for a miss are minimal, a time loss of perhaps a half second to reperform the tap. When flanked by other app icons, especially along the primary axis of movement, the performer loses much more time when a miss occurs. They may at least have to tap another icon to close the opened app and get to the desired one, or perhaps the performer must wait for the launched app to fully open before being able to close it and retry. At minimum, a second or two are lost, while the maximum consequence of missing the objective target may be 30 seconds to a minute of lost time.

The placeholder avoidance hypothesis; that participants attempt to avoid placeholder targets more than they attempt to avoid a void; contextualizes many of the findings surrounding the violation. The findings that this new hypothesis helps explain are mainly derived from the reports cited below, though some of these findings are reflected in the presently reported data. Primarily, it explains why moving to the middle target is slower; accuracy is prioritized more heavily when aiming to the middle target than it is otherwise, so speed is sacrificed. As previously stated, the hypothesis explains the undershooting that has been observed for the near target and the overshooting for the far target. It also explains the observation that the middle target is consistently overshot slightly in Glazebrook et al. (2015) though this is qualified by other findings of null results (the present study; Roberts et al., 2016) and the opposite findings (Adam et al., 2006). While aiming to the middle target, the performer feels incentivized to avoid both the near and far placeholders. Anecdotally, it was observed during the present experiment that some participants would organize their primary ballistic movement to end with the tip of their finger hovering approximately a centimeter or two above the objective target, after which the participant would make a secondary movement perpendicular to the primary axis of movement to touch the target (quantitative evidence of this phenomenon is discussed in depth in section 4.3). The parabolic arc required to perform this movement would need to have its’ endpoint on the plane created by the touchscreen farther than the center of the objective target; without the hard stop provided by the touchscreen, participants may be more likely to err in the direction of the movement rather than in the opposite direction. This also explains the reportedly counterintuitive account in Roberts et al. (2016) that overshooting and reversing is the most common secondary movement strategy instead of a more optimal reacceleration strategy. The only reason to attempt such a movement strategy would be to ensure hitting the near or far target is much less likely, as it is a very sub-optimal strategy to slow down a rapid movement to near 0m/s before making a secondary movement if the strategy is not to prioritize accuracy.

The placeholder avoidance hypothesis also explains why placeholder targets must be present during the movement planning stage for the violation to take place, yet the locus of the violation is in the secondary movements (Blinch et al., 2012; Bradi et al., 2009). Performers must observe that the obstacles exist during movement planning for their intended primary movement to be slightly altered in a way which facilitates secondary movements which prioritize accuracy. Kinematic variables; PV, PA, ttPV, and ttPA; would be predicted to have a pattern nearly consistent with a standard Fitts' Task (ie higher ID targets eliciting higher kinematic variable values) as the locus of the violation is in the secondary movements (Blinch et al., 2012) while kinematic outcomes are almost invariably extracted from primary movements. The primary movements may be slightly altered, but this change may be beyond the detection capacity of previously used methods. The present study showed that ttPA was not significantly different between the middle and farthest targets; perhaps evidence of slight alterations in the primary movement than what would be expected in a normal Fitts' Task.

There are some predictions that emerge from the placeholder avoidance hypothesis. The first prediction regards the nature of the gestalt that elicits the violation. Because this hypothesis involves performers avoiding other targets, a large outlined 'target range' that has objective targets appear within it is not predicted to elicit the violation, while previous hypotheses would predict the violation in such a scenario due to the gestalt nature of such a representation.

Similarly, it could be expected that a population that does not construct gestalts to the same degree as the general population from individual elements, such as individuals on the autism spectrum (Booth & Happé, 2018; Carther-Krone et al., 2016; Rinehart et al., 2000) would still be susceptible to violate Fitts' Law under the circumstances examined in the present study. Lastly, because the width factor of Fitts' Law only holds under circumstances where participants are incentivised to be accurate (Zelaznik & Forney, 2016), it may be expected that MT to the middle targets in a large target array are more closely modeled by Fitts' Law than to the same targets without placeholders present. This would require variations of target width, a factor not yet explored in the context of the violation.

Feasibility and Validity of a Digital Accelerometer Used to Measure a Fitts' Task

Regarding the validation of the Device, the omnibus statistical comparisons concerning acceleration-derived outcome measures yielded the same pattern of statistically significant findings for every test conducted on the most important measures (MT, RT, and PV) as the results from Glazebrook et al. (2015). The comparisons between the test results for the kinematic measures in the present study and Glazebrook et al. (2015) are also consistent with predictions. Velocity outcomes (PV, ttPV) showed identical patterns of results in both studies (Table 4). Measures directly concerning acceleration (PA, ttPA) are the only measures for which the results of statistical tests differ between studies. The disparity in acceleration measures is likely due to the relative inaccuracy of acceleration when derived from position data [from Glazebrook et al. (2015)] compared to acceleration when directly measured (from the present study). Performing a derivation on a data set exacerbates the amplitude of contaminating high frequency signals (Pezzack et al., 1977). This problem is generally solved through two methods; 1) an aggressive low-pass filter, and 2) to increase the gap between the points from which the derivative is extracted. Glazebrook et al. (2015) do not report the filter parameters or the derivation method they used, but there is evidence that they may have been overzealous with their efforts to control the high frequency noise in their signals. Peak acceleration values from the data sets Glazebrook et al. (2015) reported on hover around $4m/s^2$-$5m/s^2$, about half the magnitude of PA values measured in the present experiment. A smoothing of the peaks may have contributed to the non-significant results Glazebrook et al. (2015) reported for PA tests, as the peaks would not have been specific enough for precise identification. The attenuation of peak acceleration may have also contributed to the non-significant result for ttPA by block in Glazebrook et al (2015). As acceleration is measured directly in the present study rather than being derived from another data set, it may be considered relatively free from frequency contamination and is the more reliable measure of acceleration.

Beyond this ecological validation, comparisons between touch and acceleration derived measures show that acceleration data coming from the Device yields similar results as the touch data. As touch data has been used to examine Fitts' Law in published studies, including those considering the violation examined in the present study (Adam et al., 2006; Pratt et al., 2007), it can be considered a high standard in comparisons with acceleration-derived outcome measures. The two measures of movement onset are significantly correlated (Table 5), a slope of nearly 1 (meaning an increase of 1ms for touch movement onset occurred concomitantly with a 1ms increase for acceleration movement onset), and an extremely high correlation coefficient (R^2=0.94). The intercept for the correlation regression is -45.262ms (Equation 3). A disparity between kinematically-determined movement onset and mechanically-determined movement onset has been examined before, where it was determined that a velocity cutoff determining movement onset results in a significantly shortened reaction time than a mechanical switch (Blinch & DeWinne, 2019). Mechanical switches, including touchscreens, detect movement only after a certain position is passed. This method is thus a lagging indicator of movement when compared to kinematic methods, as acceleration and velocity must surpass a significant magnitude in order to pass the mechanically important position and continue with a planned ballistic movement. This lagging effect was observed in the touch-derived ttPA values below zero observed in some trials in the present experiment. A sub-zero touch-derived ttPA value is only possible if significant acceleration occurs before mechanical activation of the touch screen. A consistent difference between acceleration-derived movement onset and a touch-derived movement onset is predictable and should not impact the quality of event detection, which the significant correlation between the two measures demonstrates.

Movement offset as determined by acceleration and touch were also significantly correlated (Table 6). This result comes with the caveat of a smaller R^2 value of 0.584 and what seems to be a very large and unexplainable intercept of 261.38ms and slope of 0.643. Under ideal circumstances, the intercept would be 0ms and the slope would be 1 for a direct 1:1 relationship between touch-derived and acceleration-derived values. While the movement onset correlation values hew close to these ideals, movement offset values do not. Despite this, a plurality of trials are normally distributed around a value of 0 for the difference between acceleration-derived and touch derived movement offset (Figure 17). Additionally, when the intercept is set to 0 for the regression, the slope is nearly 1 (Figure 18).

Figure 24: Histogram of the difference between movement offset from acceleration and the movement offset from touch for each trial

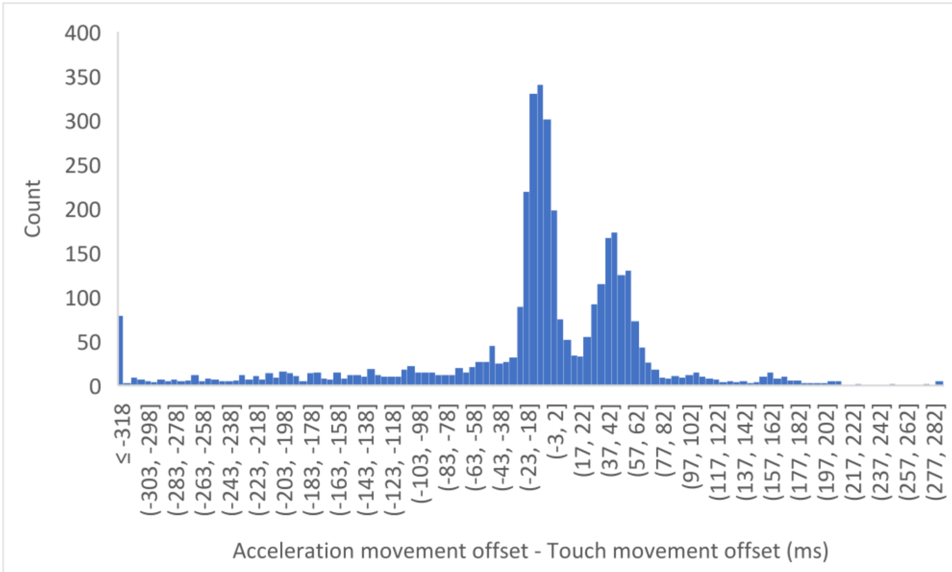
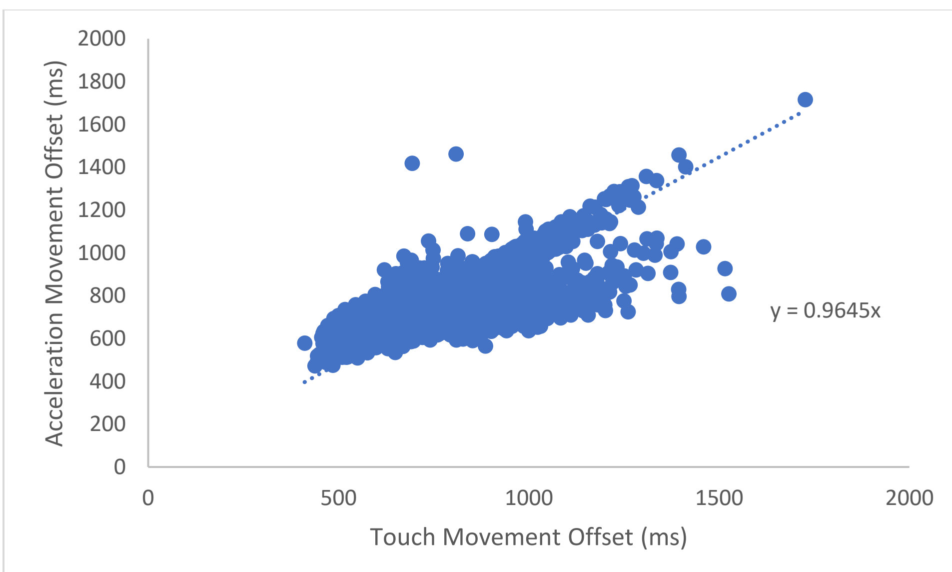


Figure 25: Linear regression of the correlation between touch movement offset and acceleration movement offset when the y-intercept is fixed at 0ms



Considering both Figure 17 and 18, the reason for the disparity between the correlation values is clear; for a minority of trials, touch movement offset is significantly longer than it should be to such a significant degree that the correlation becomes skewed. This effect is seen in the left-tailed nature of Figure 17 and the lobe of datapoints in the lower right quadrant of Figure 18. These features represent trials where touch movement offset was significantly longer than acceleration movement offset (Figure 19). When the trials that had drastically higher touch movement offset compared to acceleration movement offset were examined, late secondary submovements that occurred after the 200ms lag period, meant to catch secondary movements, were found. The data suggests that touch movement offset occurred after these secondary submovements, while acceleration movement offset occurred before the submovements. Most trials did not have drastically different touch- and acceleration-derived movement offsets, but the trials which did are concentrated in a few participants where many of their movements showed different offset times, suggesting those participants may have been using different movement strategies than the rest. The differences between mechanical and kinematic determinants of movement offset may help to explain why earlier studies concerning the violation of Fitts' Law (Adam et al., 2006; Pratt et al., 2007) found more significant results; namely that MT to the farthest position was significantly lower than MT to the middle position; than some more recent investigations, which found no significant difference between MTs to the middle and farthest targets (Blinch et al., 2012; Glazebrook et al., 2015; Roberts et al., 2016). Earlier studies may have captured the lagging secondary movements at a higher rate because they used touch screens to measure the Fitts' Task and found larger violation effects because of it, much like the results from the touch data in the present study. Glazebrook et al. (2015), for instance, would have determined the sample trial in Figure 20 to have ended before the secondary movement. This disparity poses an issue; should lagging secondary movements be counted as part of the overall movement? If there is a large time gap between the primary movement and secondary corrective submovements, at what point is it a separate movement entirely, bound by separate constraints from a proper Fitts' Task movement where both speed and accuracy are prioritized? A greater than 200ms lag between muscular impulses suggests that participants who used a stop-and-go movement strategy ceased moving nearly completely and began a separately planned movement from the original, rather than correcting errors in an ongoing movement using online control mechanisms.

Figure 26: Resultant acceleration vs. time plot of sample trial with significant difference between touch and acceleration derived movement offset with significant offset events noted

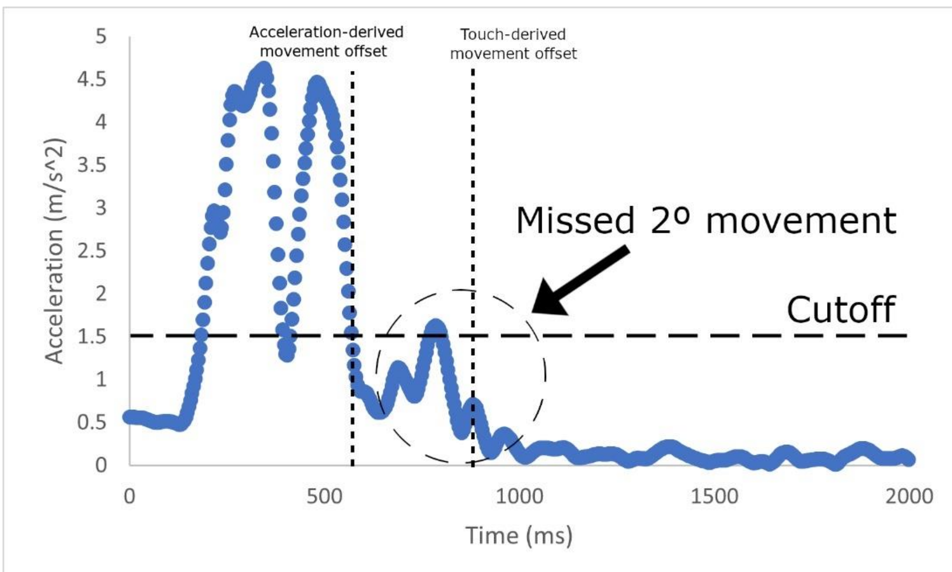
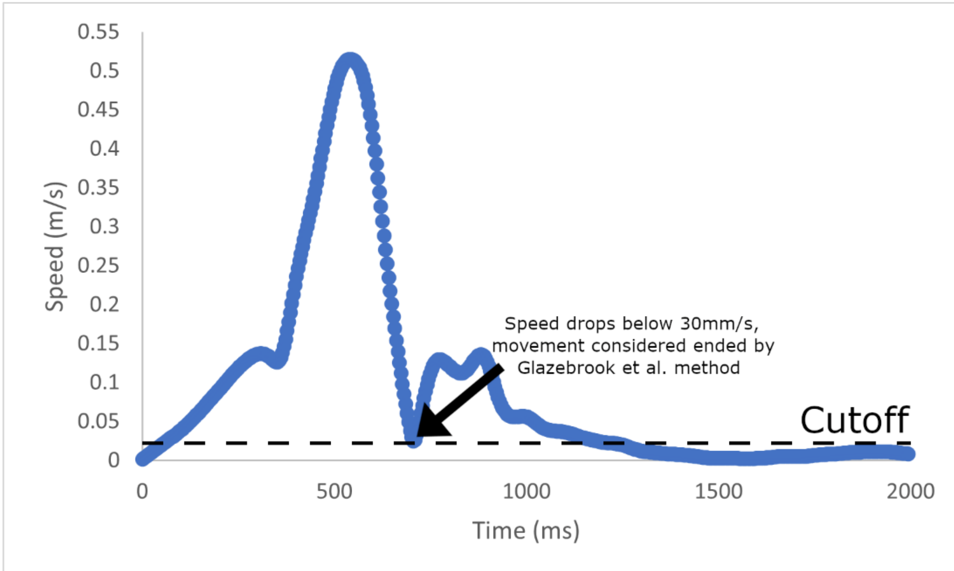


Figure 27: Resultant speed vs. time plot of sample trial with significant difference between touch and acceleration derived movement offset with significant offset events noted



There are two ways to resolve the issue that many trials have drastically longer touch-derived movement offsets compared to acceleration-derived movement offset. The first is to decouple the cutoff acceleration for the movement onset/offset determination (currently 1.5m/s^2) and lower just the movement offset cutoff. Considering the acceleration movement onset cutoff results in very closely matched times to the touch data, changing it seems unnecessary. Lowering just the offset cutoff would enable close onset modelling while also allowing for the capture of the lagging submovements. Alternatively, the lagging submovements may not be considered a part of a properly performed Fitts' Task. Considering the large delay in execution (>200ms) from the end of the primary ballistic movement, the lagging submovements may be considered separately organized movements rather than corrections of the original movements and therefore should not be considered in an analysis of movement time.

When considering Figure 17, another notable feature that resolves itself is the bimodal nature of the histogram. There are clearly two normal distributions being represented in the histogram, one with a mean difference between acceleration and touch-derived movement offset of around 0ms and the other around 45ms. The trial data distributed around 45ms appear to be movements that occurred directly after the participants touched the screen, resulting in the capture of the movements by the acceleration data but not by the touch screen. This effect is likely caused by a similar phenomenon to the movement onset differences discussed above (mechanical vs kinematic determinants of movement onset) considering their very similar temporal nature, with the caveat that this effect is not seen in all trials.

The results discussed above constitute evidence for the validity of the Device because the most important measures are the same when yielded from the standard measurement technique (touch) and the new measurement technique (acceleration). Both of the most important variables, MT and RT, are derived from the times of movement onset and offset. Both movement onset and offset as measured by touch and acceleration were found to be highly correlated (R^2 values of 0.940 & 0.584) (Tables 5 & 6). These results show that the acceleration measurement method produces similar metrics as the touch method, verifying that the acceleration method may be substituted for the touch method without changing observed outcomes. Correlations between measurement methods should be performed for other measures to confirm their conformity with standard measurement techniques which are able to yield kinematic measures, which would be a reasonable approach to take as soon as the COVID-19 crisis abates.

Feasibility was demonstrated in two dimensions: 1) through the proof of validity, showing that the Device works as intended; and 2) through the successful use of the Device by 22 untrained users with remote expert oversight (Bowen et al., 2009). Participants were able to set up and operate the Device with minimal additional guidance once the procedure was explained to them. The setup and protocol (180 trials) were completed in approximately 30 minutes per participant. Clinically focused experiments considering Fitts' Task performance in symptomatic participants are as short as 40 trials (Passmore, Johnson, et al., 2019); even the longer ones do not exceed 108 trials (Passmore et al., 2007, 2014, 2015); so the time taken for a participant to perform the task can be cut down substantially in a clinical environment. Twenty-two participants used the Device in a week and encountered no significant issues beyond one user who tried to use the equipment while it was still wet from the sanitization procedure, to which the solution was to wait 5 minutes for the glove to dry. The outcome measures were able to be put directly into statistical tests as the software incorporated into the Device automated data reduction. If any additional variables are desired that are not output by the existing program, the raw data from each trial is stored for later processing.

Overall, outcome measures derived from the acceleration data from the present study yield very similar test results to those Glazebrook et al. (2015) found. Additionally, both movement onset and offset as derived from acceleration data are highly correlated with movement onset and offset as derived from touch data. A nearly 1:1 relationship exists between changes in movement onset, and while a similar relationship does not exist for movement offset, there are explanations and solutions for this issue. Using acceleration-based methods to measure a Fitts' Task can be both feasible and valid.

Conclusions

There were two questions this study was designed to address: 1) can a novel accelerometer device and custom software feasibly and validly measure Fitts' Task performance; and 2) could the pattern of results from Glazebrook et al. (2015) be replicated. Feasibility was demonstrated through the successful use of the Device by 22 untrained users and through validation, which was shown through the test-specific replication of the pattern of results from Glazebrook et al. (2015) and comparisons to touch-derived outcome measures derived in the present experiment. The pattern of results from Glazebrook et al (2015) was successfully replicated, with both touch-derived and acceleration-derived outcome measures revealing a violation of Fitts' Law when placeholder targets are perceptually available to performers both before and during a pointing movement, with movements to the farthest target in the target array having a lower-than-expected movement time. Additionally, the placeholder avoidance hypothesis, a new hypothesis as to why the violation of Fitts' Law occurs, is discussed.

Projected Significance of Research

This study aimed to show the feasibility of a relatively inexpensive and compact device for use in measuring an upper limb Fitts' Task. This study will facilitate the use of the Fitts' Task in a wider array of environments without significantly compromising accuracy, precision, and the measurement of secondary outcome measures. New areas may include: clinical environments, where cost and space are an issue; remote and field environments, where access to electricity and transportation of bulky equipment may be difficult; and classroom environments, where costs and fragility create restrictions. More accessibility should facilitate the use of the Fitts' Task in new populations and applications, reduce costs, and increase the versatility of the task. Though this study did not use the most modern Gold-Standard equipment directly, it ideally showed that similar results are gained from the Device as are gained from the Gold-Standard equipment. A real validation study, directly comparing results for the same movements made by the same people, will be needed to be sure of the reliability of the Device, and a study like this will follow once COVID-19 related restrictions abate.

This study was also a replication of a study with the objective to parse the contribution of the planning hypothesis of why violations of Fitts Law occur in the specific circumstances to be presented by this study. Replication studies have historically not been common in the motor behaviour field; yet they are necessary for the scientific process to proceed properly. Replication is needed to show that results are not probabilistic flukes and that methods are sound. This study thus served as a test of Glazebrook et al. (2015) and generated a hypothesis as to why this violation of Fitts' Law occurs. The new hypothesis will hopefully fuel further study of this phenomenon and improve our understanding of human movement and improve our ability to interact with the world around us with minimal error.

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Appendix: Informed Consent Form

Research Project Title: *Feasibility of a tri-axial digital accelerometer for use in an upper limb Fitts' Task: Replication of a gold-standard technology*

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This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

A brief description of the purpose of the research

The purpose of this study will be to see if the device developed by the research team ('the New Device'), which measures acceleration, can produce the same results as the equipment used by many other researchers ('the Old Equipment') to measure a kind of movement task called a Fitts' Task. The equipment used by other researchers measures position instead. To perform a Fitts' Task, a person points at a series of targets of various sizes and distances away from the person as quickly and accurately as possible. This activity allows a researcher to better understand the person's motor system.

A description of the procedures involving the participant

We will compare the New Device to the Old Equipment by having you equip yourself with the New Device and having you perform a single series of Fitts' Task trials, the results of which will be compared against results from a study conducted with the Old Equipment. The New Device consists of a small device that measures acceleration, which will be mounted to the wrist and index finger of your dominant hand, and a laptop computer, which will present targets for you to point at and store the acceleration data. For the experiment, you will then be asked to face the laptop computer screen placed in front of you and perform the Fitts' trials. Each of the trials will start with you placing your dominant index finger on the white square that appears on the left side of the screen (the 'home position') and holding there until a new square appears to the right of the home position after 1.5-2.4 seconds. You will then move as quickly and accurately as possible to point at the new square with your right index finger, hold there until it disappears 2 seconds after it appeared, and move back to the home position once you want to start the next trial. This will be repeated 180 times. You may take a break at any point between trials. The entire process will take approximately 15-30 minutes.

The experiment will take place at your place of residence or other private location in which you feel safe. The study equipment will be dropped off at your house for you to administer the test to yourself, after which it will be picked back up. No staff member will enter your location of choice. During the experiment, we will ask that you engage in a video call with a staff member so they may answer any questions you have during the experiment and ensure you are performing the task properly. We will wear a mask, gloves, and use hand sanitizer while handling the equipment. We will ask you to wear a mask and use hand sanitizer before handling the equipment as well. We will also sanitize the equipment before we drop it off, and will ask you to sanitize it after you receive it before you do the experiment and again before you return it to us with sanitizing fluid we will provide you.

A description of the recording devices to be used

The New Device consists of a circuit board that measures acceleration connected to a processor that then interprets and sends that acceleration information to a computer. The acceleration measuring circuit board and processor are attached to your wrist and right index finger. The computer displays targets, collects touch information from its' touch screen and acceleration data from the device mounted to your hand, analyzes, and stores that information.

A description of the benefits of participation

You will directly benefit by being able to participate in and learn about the research process. You may indirectly benefit by having this technology available to address your or your loved ones' health concerns later in life when this technology has been further developed.

A description of the potential risks of participation

This research is being conducted at a time in which a global pandemic is occurring. All reasonable steps will be taken to minimize the risk of transmitting COVID-19 through this experiment, including; no direct or close-to-direct human-to-human contact will take place over the course of this study, all surfaces of the research equipment will be sanitized between exchanges by both the experimenter and the participant, a personal motor vehicle will be used by the experimenter to get to and from the research location, the research location will be the your place of residence which the experimenter will not enter to conduct the experiment, hand sanitizer will be required to be used by the experimenter and you before handling research equipment, the experimenter and you will be required to wear masks while handling the research equipment, the experimenter will wear gloves while handling the research equipment, and the experimenter and you will be screened for symptoms of COVID-19 by the experimenter before transferring research equipment. However, you will be required to come into contact with the testing equipment handled by the experimenter, creating a risk of exposure to COVID-19. A record of all participants, the time and date at which they used the equipment, and their contact information will be kept in a secure location until the end of the study, upon which time this information will be deleted. If COVID-19 exposure is suspected, you will be informed of the suspected date of transmission and when you participated in this experiment, and recommended to seek a COVID-19 test.

An indication of whether the data will be anonymous (contain no personal identifiers) or confidential (contain personal identifiers) and the steps the researcher will take to protect confidentiality

Two sets of data will be collected; anonymized data to be analyzed to yield results for this experiment, and confidential personally identifying information which is to be used to contact you should COVID-19 exposure be suspected, to keep a record of your consent to participate in this study, and so that you may be sent a summary of the results of this study if you wish. To protect your personal identifying information, it will be kept within electronic documents on a secure University of Manitoba email server. Only the Primary Investigator and his graduate studies advisor will have access to this personally identifying data. They will access it only if COVID-19 exposure is suspected to have occurred during the experiment or to send you a summary of the findings of this study. If this personally identifying data should be exposed to the wrong person, they may be made aware of your contact information and the address at which you performed this experiment. The data collected to be analyzed during this study will not be associated with your personally identifying information; a number will be assigned to your data instead of your name. This should make it difficult or impossible to tie the data collected from you for analysis to your person. If this anonymized data is tied to you by the wrong person, they would know how you performed on a Fitts' Task.

A description of any form of credit or remuneration for participating

You will receive no monetary compensation for your participation in this study.

A description of how the participant may withdraw

You may withdraw from this study at any time without consequence to yourself by informing the research staff member administering the tests during the experiment that you wish to withdraw, by contacting the research staff through the channel in which you were recruited, or through the contact information provided above. This must be done before the experimental phase of the study concludes, around the middle of April 2021.

A description of the debriefing that will be provided

If you have any questions about the experiment being conducted before, during, or after the experiment, feel free to ask the research staff via the contact information above or in conversation with them. No information will be withheld at any point before, during, or after the experiment.

A description of how research results will be disseminated

Research results may be disseminated through a thesis, journal articles, and conference presentations. No personally identifying information will be shared in these forums.

A description of how and approximately when a brief (1-3 pages) summary of results will be provided

At your discretion, a 1-3 page summary of results will be provided to you approximately in July 2021. If you wish to receive this, please fill out the form the research staff member sends you. You will be sent this summary when it is complete to the contact you provide.

A description of how and approximately when confidential data will be destroyed

The forms containing your personally identifying information will be deleted from the server they are stored on approximately 2 weeks after the experimental phase of the study concludes, around the middle of April 2021, after the chances of any COVID-19 transmission occurring because of this research becomes minimal. The forms containing the contact at which you may wish to receive a summary of results will be deleted after one is sent to you. This consent form will be stored indefinitely as a record of your consent. Anonymized experimental data will be kept indefinitely.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Research Ethics Board at the University of Manitoba, Fort Garry campus. **If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator at 204-474-7122 or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.**

Participant’s Name ________________________

Participant’s Signature _________________________ Date ____________

Researcher and/or Delegate’s Signature ____________________ Date _______