Evaluating Fitts' Law on Vibrating Touch-Screen to Improve Visual Data Accessibility for Blind Users

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Abstract—**The pointing task is the process of pointing to an object on a computer monitor using a pointing device, or physically touching an object with the hand or finger. It is an important element for users when manipulating visual computer interfaces such as traditional screens and touch-screens. In this context, Fitts' Law remains one of the central studies that have mathematically modeled the pointing method, and was found to be a good predictor of the average time needed to perform a pointing task. Yet, in our modern computerized society, accessing visual information becomes a central need for all kinds of users, namely users who are blind or visually impaired. Hence, the goal of our study is to evaluate whether Fitts' Law can be applied for blind candidates using the vibration modality on a touch-screen. To achieve this, we first review the literature on Fitts' Law and visual data accessibility solutions for blind users. Then, we introduce an experimental framework titled *FittsEVAL* studying the ability of blind users to tap specific shapes on a touch-screen, while varying different parameters, namely: target distance, target size, and the angle of attack of the pointing task. Experiments on blindfolded and blind candidates show that Fitts' Law can be effectively applied for blind users using a vibrating touch-screen under certain parameters (i.e., when varying target distance and size), while it is not verified under others (i.e., when varying the angle of attack). This can be considered as a first step toward a more complete experimental evaluation of vibrating touch-screen accessibility, toward designing more adapted interfaces for the blind.**

Keywords—***Blind users, pointing method, visual data accessibility, Fitts' law, vibrating touch-screen.***

1. Introduction

In human-computer interaction (HCI), the *pointing task* (also known as the *pointing method*) is the process of visually pointing to an object on a computer monitor using a pointing device, or physically touching an object with the hand or finger. It is an important element for users when accessing data through computer devices with graphical interfaces such as traditional screens (using the mouse as a pointing device) – and more recently touch-screens (using one's finger to point to targets), where information is presented through graphical user interfaces (GUIs) made of panes, frames, menu bars, and images, etc. While various studies have addressed the pointing task in the past three decades, e.g., (Beggs W. et al., 1972; Card S.K. *et al.*, 1978; Drury C.G., 1975; Glencross D. and Barrett N., 1983; Sasangohar F. *et al.*, 2009), one of the most recognized remains Fitts' Law (Fitts P. M. and Peterson J. R., 1964) that predicts the average time needed to perform the point task w.r.t. (with respect to) different parameters. Fitts proved that the time needed to move to a target zone is a function of the distance to the target and the target's size (Fitts P. M., 1954). Fitts' Law and most of its related studies focus on users with normal eye sight. Yet in our modern computerized society flooded with visual media tools and applications (Web pages, graphics, animations, mobile applications, etc.), accessing visual information becomes a central need for all kinds of users, namely users who are blind or visually impaired.

Following its latest statistics, the World Health Organization (WHO) estimates at 285 million the number of people affected by visual impairments, among which 39 millions are totally blind; these numbers are even expected to double by the year 2020 (World Health Organization, 2014). However, thanks to adapted tools of assistance (e.g., screen readers, digitalized Braille terminals, screen magnifiers, etc.), computerized solutions are increasingly helping persons with visual impairments to access and manipulate information, and perform various kinds of activities previously deemed unfeasible for blind or visually impaired users. While effective with textual contents, e.g., (ANSI/NISO, 2005; Cooper M. *et al.*, 2008; Dolphin, 2016; Guillon B. *et al.*, 2004; Stephan F. and Miesenberger K., 2008), yet existing solutions remain limited when it comes to accessing and understanding visual contents and graphical interfaces. In most cases, given an input text-based document, the output is a text-only document with a transcription of the structure, content, and illustrations from the original document, such that the transcription is accessible to blind users via tactile (e.g., Braille print[1]) or acoustic (e.g., text-to-speech) means.

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[1] The Braille system is a method based on tactile contact, widely used by visually impaired people in order to read and write text. A Braille character is made of six dot positions, arranged in a rectangle containing two columns of three dots each. A dot may be raised at any of the six positions to form sixty-four (2^6) possible subsets (character encodings), including the arrangement in which no dots are raised.

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Some (software-based) studies have targeted accessibility to text-based visual contents, namely Web pages and graphical contents, using adapted screen readers, and talking browsers (Apple, 2016; Bou Issa Y. *et al.*, 2010; Bou Issa Y. *et al.*, 2009; Caleb S. *et al.*, 2012; Semaan B. *et al.*, 2013; Shaun K. *et al.*, 2008). An interesting study in (Bou Issa Y. *et al.*, 2010; Bou Issa Y. *et al.*, 2009) focuses on the design and visual arrangement of text-based objects in a Web page, in order to improve its presentation using embossed paper printouts. Yet, they focus on (text-containing) Web graphics and the visual arrangement/ design of (text-based) objects in a Web page, and do not specifically target (text-free) images. In other words, accessing (text-free) visual graphics and images (i.e., images without textual annotations) remains an ongoing challenge. Other (hardware-based) techniques have utilized haptic feedback: using a force feedback mouse (Yu W. and Brewster S. A., 2002), piezo-electric pins (Pietrzak T. *et al.*, 2009), or external vibrators fixed to the user's fingers (Goncu C. and Marriot K., 2011) in order to access images (Abu Doush I. *et al.*, 2012), mathematical charts and geographic maps (Kaklanis N. *et al.*, 2011). Yet, they remain quite expensive, of limited use (single-purpose), and of limited portability (where bulky equipments are usually required and need to be configured for every device and user) (Maclean K.E., 2008).

Nonetheless, the unprecedented proliferation of vibrating touch-screen based devices (e.g., smart-phones and tablets) has opened the door to a new era of haptic vibration interfaces, where finger movements over the display provide position and orientation indicators through synchronized audio and vibration signals which are delivered when the user touches a visual element on the touch-screen. The vibrating touch-screen technology presents many opportunities as: i) an affordable (cost-efficient) solution (compared with existing expensive accessibility tools), ii) a solution based on off-the-shelf commercial hardware (compared with highly specialized equipment), and iii) a solution which is portable and can be deployed in different contexts and environments (compared with specialized and single-purpose devices). In this context, several authors in (Awada A. *et al.*, 2012; Awada A. *et al.*, 2013; Giudice N. A. *et al.*, 2012) have recently addressed the accessibility of simple visual representations (basic shapes and contours) on vibrating touch-screens (the solution in (Giudice N. A. *et al.*, 2012) supports vibration and audio, whereas the authors in (Awada A. *et al.*, 2012; Awada A. *et al.*, 2013) investigate vibration-only accessibility), highlighting the potentials of the technology. Nonetheless, simple (contour-based) image presentations in (Awada A. *et al.*, 2012; Awada A. *et al.*, 2013; Giudice N. A. *et al.*, 2012) do not necessarily respect the standards and norms of tactile presentations (e.g., stipulating that a single contour line is at least 1 to 2 millimeters thick whereas the separation between two contour lines is at least 3 millimeters thick, and considering Fitts' Law in designing and locating pointing targets on the GUI, etc.) (SOCRATE-COMENIUS, 2000), since the resulting image is to be presented on a vibrating screen, and not on an embossed paper. In this context, a dedicated experimental study is required to evaluate the difference between tactile perception (for a blind user) on an embossed paper on one hand, and perception on a vibrating screen on the other hand, in order to adapt image and visual data presentation accordingly.

The focus and goal of our current study is to evaluate whether Fitts' Law can be applied for blind candidates using the vibration modality on a touch-screen. Evaluating the pointing task for blind users utilizing a vibrating touch-screen can serve many practical needs and applications, namely: i) enhancing blind-computer interaction by adding the perception of simple 2D targets (such as buttons and panels) in the interaction process (Giudice N. A. *et al.*, 2012; TextHelp, 2016), ii) improving on the capabilities of existing mouse or keyboard controlled assistive technologies (Mishra P. and Shrawankar U., 2014) to facilitate accessing graphical information on a computer screen (such as pointing to folder or file icons on a computer desktop), iii) enhancing geographic navigation in maps, indoor navigation, and perception of roads and points of interest (by perceiving and following simple vibration pointers on the touch-screen (Giudice N. A. *et al.*, 2012; Poppinga B. *et al.*, 2011), and iv) enhancing navigation assistance in user interfaces (such as graphical software interfaces, Web pages, or adapted ATM[2] machine interfaces (Bou Issa, 2010; Bou Issa Y. *et al.*, 2010)) by including specially tailored vibration indicators and pointing tasks, and introducing new navigation models based on such pointing tasks (compared with embossed paper indicators used in existing methods (Bou Issa Y. *et al.*, 2010; Bou Issa Y. *et al.*, 2009)). To our knowledge, this is the first approach to study the applicability of Fitts' Law for blind users using a vibrating touch-screen. To achieve this, we design an experimental framework titled *FittsEVAL* (Fitts' Law Evaluation of Vibration AccessibiLity), in order to test a blind user's ability to tap specific shapes on a touch-screen. A dedicated prototype system has been developed to implement the proposed experimental framework. Experiments on blindfolded and blind testers show that Fitts' Law can be effectively applied for blind users under certain parameters (i.e., when varying target distance and size), while it is not verified under others (i.e., when varying the angle of attack). Our present contribution can be considered as one part of a larger experimental study investigating vibration touch-screen accessibility for blind users (that our team has been developing for the past couple of years), targeting the identification, recognition, and manipulation of simple images and graphics on a vibrating touch-screen (Awada A. *et al.*, 2012; Awada A. *et al.*, 2013; Semaan B. *et al.*, 2013; Tekli J. *et al.*, 2017). The remainder of this paper is organized as follows. Section 2 reviews the background on Fitts' Law and related pointing methods and applications. Section 3 develops our experimental framework to evaluate the performance of Fitts' Law for blind users using a touch-screen. Experimental results are presented and discussed in Section 4, before concluding in Section 5 and highlighting future works.

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[2] Automated Teller Machine

2. Background, Related Works, and Applications

In this section, we present a brief overview of Fitts' Law and studies addressing the pointing task, and related applications.

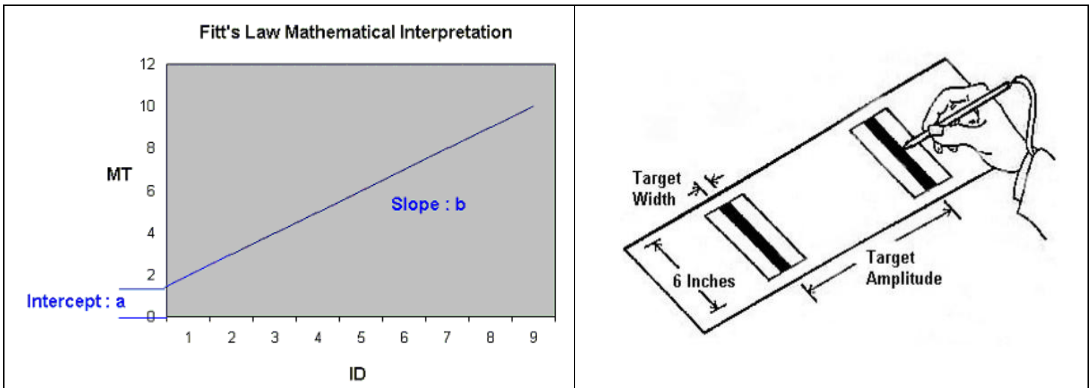
2.1. Fitts' Mathematical Model

Fitts' Law is a model of human psychomotor behavior developed in 1954 (Fitts P. M., 1954). Building on Shannon's theorem in information theory and using it to describe the human perceptual-motor system, Fitts came up with a formal connection that displays speed/accuracy tradeoffs in quick and aimed movements. Following Fitts' Law, the time to move and point to a target of width *W* at amplitude (distance) *A* is logarithmically related to a structural relation error expressed as ratio *A*/*W*, formally:

$$MT = a + b \log_2\left(\frac{2A}{W}\right) \qquad \textbf{(1)}$$

where: *MT* is the movement time, *a* and *b* are device dependent constants, *A* is the amplitude (or distance) of movement from the source object's center to the target object's center, *W* is the width of the source and target objects[3], which relates to pointing *precision*, and factor $\log_2\left(\frac{2A}{W}\right)$ represents the index of difficulty (*ID*) required to achieve the task (following information theory's *bits* metric). It is a linear regression model, where regression coefficients: *a* representing intercept, and *b* representing slope (cf. Figure 1.a) are determined empirically. Physically explained, Fitts' Law reveals the following observations: i) big targets at closer distances are caught quicker than small targets at farther distances, ii) *ID* gives a single combined amount of the two main physical properties of the movement task (i.e., distance *A* and width *W*), iii) *ID* is raised by one unit for each duplication of *A* and bisection of *W*, iv) positive intercept *a* is an additive element distinct from *ID*, which can affect the motion and/or selection mechanisms of a device (e.g., mouse, button, etc.), and v) $\frac{1}{b}$ represents the index of performance (*IP*, in *unit of time/bit*) which evaluates the information capacity of the human motor system.

The original investigation of Fitts' Law in (Fitts P. M., 1954) involved four experiments: two reciprocal tapping tasks (l-oz stylus and 1~lb stylus), a disc transfer task, and a pin transfer task. In each of the tapping tests, participants move a stylus back and forth among two metal bars as fast as possible and tap the bars at their centers (cf. Figure 1.b). This experimental display is frequently named the "Fitts' paradigm".



a. Fitts' Law, as a linear regression model.

b. The reciprocal tapping paradigm (Fitts P. M., 1954).

Figure 1. Fitts' Law's regression model, and its tapping paradigm.

Few variations of the law have been suggested, namely by Welford (Welford A. T., 1968) (cf. Formula 2), and Mackenzie (MacKenzie I.S., 1992) (cf. Formula 3), which were later acknowledged by Fitts (Fitts P. M. and Peterson J. R., 1964):

$$MT = a + b \log_2\left(\frac{2A}{W} + 0.5\right) \qquad \textbf{(2)}$$

$$MT = a + b \log_2\left(\frac{A}{W} + 1\right) \qquad \textbf{(3)}$$

The suggested models have been extensively compared with Fitts in various studies, e.g., (Beggs W. et al., 1972; Card S.K. *et al.*, 1978; Drury C.G., 1975; Glencross D. and Barrett N., 1983; Kerr B. A. and Langolf G. D., 1977; Kerr R., 1978; Knight A. A. and Dagnall and P. R., 1967), indicating that both Welford's and MacKenzie's formulae produce results which are usually very

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[3] Assuming that both the source and target objects have the same width (*W*) renders the pointing task direction independent (moving from source-to-target becomes equivalent to moving from target-to-source).

close to, and sometimes (under certain conditions) are even more correlated with actual human pointing behavior than results obtained from Fitts' model. Nonetheless, most researchers in the fields of motor behavior and HCI usually adopt Fitts' Law in its original formulation, which is still considered as the main reference in conducting most of their experimental studies, e.g., (Buck L., 1986; Epps B.W., 1986; Georgopoulos A. P. *et al.*, 1989; Kantowitz B. H. and Elvers G. C., 1988; Wall S. A. and Harwin W. S., 2000).

2.2. Early HCI Applications on Fitts' Law

Although Fitts only published two articles on his law (Fitts P. M., 1954; Fitts P. M. and Peterson J. R., 1964), yet it has been adopted in conducting hundreds of studies and projects published in the Human Computer Interaction (HCI) literature (Soukoreff R. W. and MacKenzie S. I., 2004), with hundreds of other studies published in the larger psycho-movement literature (Chernyak D.A. and Stark L.W., 2001). One of the early HCI applications of Fitts' Law is by Card *et al.* in (Card S.K. *et al.*, 1978), where the authors employ the index of performance ($IP = 1/b$) in order to distinguish between the performance of various input devices. Card *et al.*'s experiments use a point-select task, where participants start each test by pressing the space bar and then achieving the pointing task with the same hand. Participants control the cursor and choose targets composed of highlighted text on a display. Four pointing devices (i.e., mouse, joystick, step keys, and text keys, cf. Figure 2) are compared to measure how fast each device is able to select text on a CRT[4] display. The mouse is shown to be the fastest pointing device, as well as the device to produce minimal error rates. The authors also show that modifications in positioning time using both the mouse and the joystick can be closely followed and can be modeled using Fitts' Law. Due to Fitts' Law's characterization of the mouse, this central study by Card *et al* (Card S.K. *et al.*, 1978) was a major factor leading to the mouse's commercial introduction with computer systems.

2.3. Fitts' Law Applied and Evaluated with Movement

Jagacinski *et al.* in (Jagacinski R.J. et al., 1980) focus on testing if Fitts' Law is applicable on moving targets. The authors try to apply Fitts' Law to a target acquisition task by manipulating a joystick in order to lead the cursor between the two moving target lines as fast as possible. After each trial, the system blanks for three seconds, and then the next trial begins. The authors show that the log-linear function $\log_2 \frac{2A}{W}$ presents an acceptable estimation which matches with the experimental results for the velocity control system of the moving targets at hand. Yet, for the position control system, $\log_2 \frac{2A}{W}$ is shown not to be a suitable estimation for time capture.

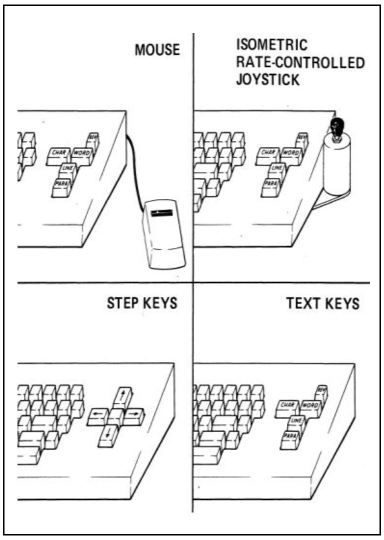

Figure 2. Pointing devices tested in (Card S.K. *et al.*, 1978).

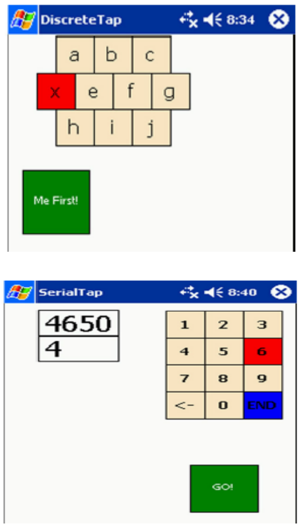

Figure 3. Discrete target phase (top) and serial target phase (bottom) in (Pekka P. *et al.*, 2006).

Subsequently, the authors in (Jagacinski R.J. and Monk D.L., 1985) test Fitts' Law on discrete manual and head movements in a target acquisition task. Subjects use either a joystick or a helmet-mounted sight to manage a cursor present on a CRT display. Each trial starts with the cursor in the middle of the exhibit and the display of a circular target on the screen. Participants move the cursor as fast as possible to the desired goal and select it. Four seconds after the goal is caught, a new trial starts with the display

[4] A cathode ray tube (CRT) monitor is an analog computer display or television set with a large, deep casing. It uses streams of electrons that activate dots or pixels on the screen to create a full image.

of the centering circle. Capture time is determined as the duration: starting with the display of the target and finishing with the start of the 344 ms capture period. The authors show that Fitts' law is applicable with both devices. More in particular, results show that relations between *MT* and *ID* are very high (r = 0.99) for both equipments, producing intercept regression coefficients of 268 ms with the helmet-mounted sight and 303 ms with the joystick. The regression line slope obtained with both devices is199 ms/bit (*IP* = 5 bits/s). Average movement times are a bit higher on the diagonal axes for the joystick (7.2%) than for the helmet-mounted sight (9.1%). Note that errors cannot occur since the selection criterion dwells inside the target.

2.4. Fitts' Law with Trajectory-based HCI Tasks

Different from Fitts' experiments which only focus on pointing to targets, computer input devices are increasingly used for producing trajectories such as moving in 2D/3D worlds, drawing curves, and writing using fingers or digital pens on touch-pads or touch-screens. Given that tracing, pursuit tracking, and constrained motion are essential for today's data access and manipulation needs through dynamic GUIs, recent studies in (Accot J. and Zhai S., 1997; Friedlander N. *et al.*, 1998) have investigated the possible regularities in human movement that can be modeled in tractable mathematical equations. The authors in (Accot J. and Zhai S., 1997) show that achieving the goal-crossing task usually depends on the relationship between movement time, movement distance, and the size of the goal width, which also resonates with Fitts' Law. In particular, the time required to click on a target of width *W* situated at a distance (amplitude) *A* (Figure 4.a), and the time required to cross a target of width *W* situated at a distance *A* (Figure 4.b) can be closely modeled following Fitts' Law's extension by Mackenzie (MacKenzie I.S., 1992) (cf. Formula 3). Nonetheless, authors in (Accot J. and Zhai S., 1997) affirm that their study on goal-crossing needs to be further developed and investigated toward building more sophisticated crossing-based interfaces.

Another study in (Friedlander N. *et al.*, 1998) investigates non-visual "bullseye" menus where the menu items ring the user's cursor in a set of concentric circles divided into quadrants (cf. Figure 5). Non-speech audio cues (played without spatialization) indicate when the user moves across a menu item (using a simple beep). A static evaluation of bullseye menus shows them to be an effective non-visual pointing and crossing technique, where users are able to select items by simply using sounds. The authors also show that users are able to place the stylus anywhere on the tablet, press down the stylus button, move the stylus in the given direction for the given number of signals (either tactile pulses or beeps) while keeping the stylus button pressed, and release when the target is reached. For instance, given that the target is EDIT copy in Figure 5, the user is told that she should go to ring 4 in the right direction, then she knows she must detect 4 feedback signals (tactile or audio beeps) in order to reach it. Nonetheless, empirical results from (Friedlander N. *et al.*, 1998) match closer with a simple linear model (cf. Formula 4) than with Fitts' Law and its extensions (cf. Formulas 1-3).

$$MT = a + b.x \qquad \textbf{(4)}$$

where *x* is the index of the target ring, and *a* and *b* are experimentally determined constants that are device dependent.

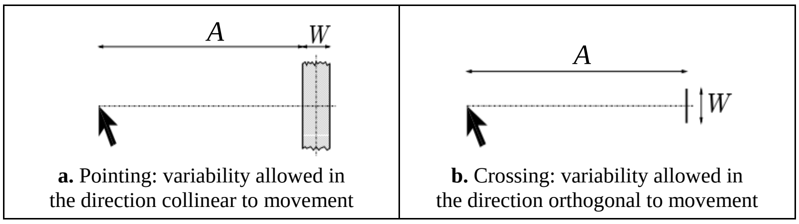

Figure 4. Pointing vs. crossing: the experimental paradigms differ in the direction of the variability allowed in the termination of movement.

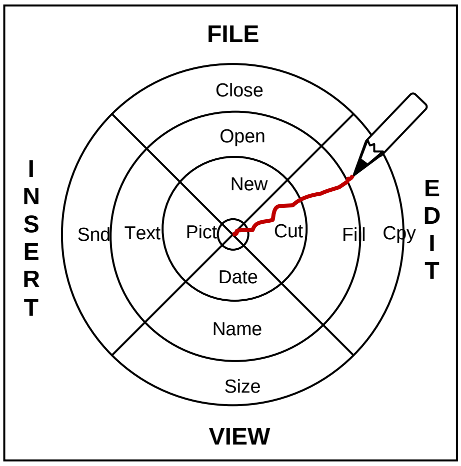

Figure 5. Selection from a sample bullseye menu (Friedlander N. *et al.*, 1998).

To sum up, Fitts' Law has been proven effective in modeling the pointing task using different devices (e.g., mouse, joystick, step keys, and text keys), where the time needed to move to a target is a function of the distance to the target and the target's size (Card S.K. *et al.*, 1978; Fitts P. M., 1954). Also, it fairly describes the pointing task applied on moving targets (Jagacinski R.J. and Monk D.L., 1985; Jagacinski R.J. et al., 1980), where Fitts' index of difficulty (*ID*), i.e., $\log_2\left(\frac{2A}{W}\right)$, presents an acceptable estimation for the velocity control system of the moving targets, but not for the position control system. Fitts' Law's extension by

Mackenzie (MacKenzie I.S., 1992) reasonably models the trajectory tracking task with a cross-based interface (Figure 4.b), but not so well with a ringed bullseye interface (Figure 5) where a simpler linear model seems to better match the task (Friedlander N. *et al.*, 1998) compared with Fitts' Law and its extensions. However, note that tasks in (Friedlander N. *et al.*, 1998) have intermediate targets between the original (source) position of the pointing device and the (final) target position, whereas there are no intermediaries between the source and target positions with Fitts' experiments, which might explain the mismatching with Fitts' model. Note that we adopt Fitts' (simpler) scenario in our current study, i.e., considering fixed targets with no intermediaries (which we will later extend to consider intermediary targets in a dedicated study).

2.5. Fitts' Law with Touch-Screen Devices

A few studies have been conducted to determine optimal target sizes for one-handed thumb use of a handheld mobile device equipped with a touch-screen (Pekka P. *et al.*, 2006). The authors in (Pekka P. *et al.*, 2006) develop instructions similar to Fitts' Law describing the user's interaction with pointing targets during one-handed thumb-use of touch-screen based devices. Accordingly, a two-part study is designed taking into account: i) discrete and ii) serial tasks (cf. Figure 3). The discrete task is composed of single targets such as selecting a checkbox, clicking a button or a menu; whereas the serial tasks are composed of multiple targets such as numeric or text entry tasks. Experiments conducted on a PDA[5] touch-screen produce results similar to those of Fitts' Law, such that the bigger an object and the closer it is, the easier the subject is able to move toward it. Results in (Pekka P. *et al.*, 2006) also suggest that users spend more time with a single discrete task than with a serial one.

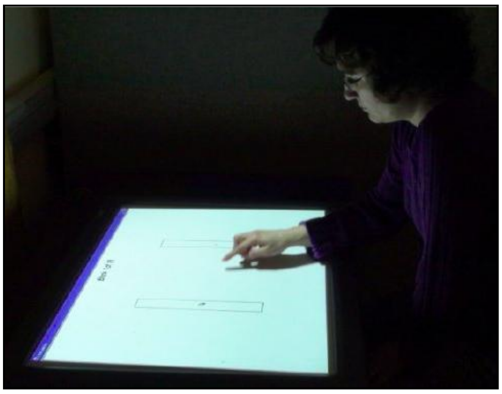

Figure 6. Pointing test on a tabletop touch-screen in (Sasangohar F. *et al.*, 2009).

In a more recent study in (Sasangohar F. *et al.*, 2009), the authors conduct similar tests on a tabletop touch-screen (cf. Figure 6), and highlight similar observations which also concur with Fitts' Law. Compared with the mouse, the authors in (Sasangohar F. *et al.*, 2009) argue that touch input can be considered as a preferred and more efficient input technique for tabletop displays, with further improvements needed to improve touch selection for small targets.

Yet, to our knowledge, Fitts' Law has not yet been evaluated for blind users utilizing touch-screens.

3. Experimental Framework

The goal of our work is to evaluate Fitts' Law on a touch-screen for blind users. We aim to prove the following hypothesis: *Fitts' Law can be applied for blind users executing the pointing task on a vibrating touch-screen*. This is an essential prerequisite for developing more sophisticated visual data accessibility and navigation techniques for blind users (as discussed in the introduction).

In order to prove this hypothesis, we develop a dedicated experimental framework, titled *FittsEVAL* (Fitts' Law Evaluation of Vibration AccessibiLity), consisting of: i) an experimental protocol describing the various steps to be followed by a test *coordinator* (e.g., a normally sighted person), in order to administer a set of experiments regarding the pointing task on a touch-screen to a *tester* (e.g., a blind or blindfolded person); and ii) an experimental prototype system, implementing *FittsEVAL*'s protocol on a (relatively) inexpensive devise with portable software interfaces, allowing to easily run *FittsEVAL*'s tests and perform corresponding experimental measurements. Our experimental prototype and protocol are described in detail in Sections 3.1 and 3.2 respectively.

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[5] Short for Personal Digital Assistant: a handheld device that combines computing, phone/fax, Internet and networking features. PDAs are now considered obsolete with the widespread adoption of smart-phones.

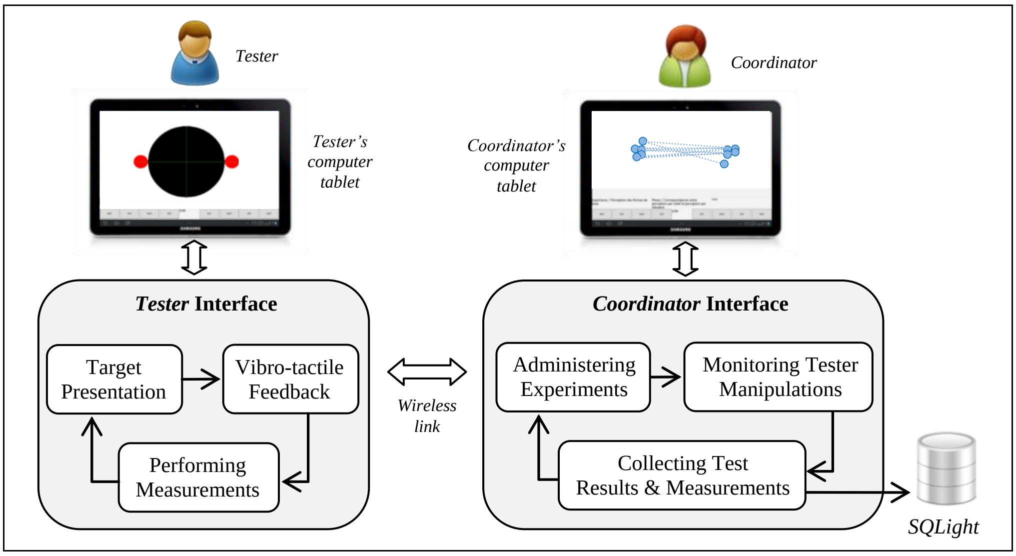

Figure 7. Overall prototype system architecture.

3.1. Prototype System Overview

Our prototype system was developed on a mobile computer tablet (Samsung Galaxy Tab) with a 10.1 inch touch-screen, a 1280×800 screen resolution, running an Android operating system (version 3.2). The prototype consists of 2 main application modules: i) the user (*tester*) interface, and ii) the *coordinator* interface, each designed to run on a separate tablet, connected together via a synchronized wireless link (cf. prototype architecture in Figure 7). On one hand, the *tester* interface is manipulated by the test subject. It provides the *tester* with pointing targets (e.g., of different sizes, distances, and angles) displayed on the tablet's vibrating touch-screen, and captures the finger tappings of the *tester* while attempting to touch the targets (among a battery of experimental measurements described in Section 4). On the other hand, the *coordinator* interface allows administering the test: acquiring *tester* profile data in the beginning, and then allowing to go from one experimental test phase to another, while monitoring *tester* manipulations and recording *tester* answers, as well as test phases execution time. An SQLite database on the *coordinator* tablet is utilized to organize and store the experimental data (i.e., measurements collected from the *tester* interface, and tester answers collected from the *coordinator* interface), synchronized with a MySQL database for later processing on a personal computer.

Regarding the tester interface, vibro-tactile stimuli are generated using the tablet's embedded electromagnetic actuator: an off-balance motor controlled by an embedded haptic player (developed by Immersion Corporation[6]). Vibro-tactile effects are configured and handled using the Universal Haptic Layer (UHL) package[7], a JAR file containing classes and methods allowing the creation and manipulation of haptic effects on Android devices (we imported UHL as a plug-in to our JAVA Eclipse development platform to create the tester interface's experimental code). While many haptic stimuli can be manipulated and tested in this interface, yet in our current study, we use a pre-defined set of parameters established from earlier studies (Giudice N. A. *et al.*, 2012; Raja M. K., 2011): where the authors identify the vibro-tactile line width which is most conducive to line/contour tracing/following, and the vibration frequency which is best perceived by testers. Hence, based on the latter findings, we present our pointing targets with a minimum inter-target distance of 8.9 mm (0.35 inch), which corresponds to 56 pixels on the tablet's screen (minimal distance perceivable by a tester on a touch-screen). The tester receives a constant pulsing vibration, given in the region covering the surface of the pointing target, with a strong repeating wide pulse at a frequency of 10-20 milliseconds (rendered using UHL's *Weapon_1* effect) whenever and as long as the tester' finger touches a target on-screen. Vibration feedback stops when the tester's finger: i) touches outside of the target's surface, or ii) releases the screen. Note that testers were instructed to use one finger only, namely the index finger, in perceiving and pointing to images on the tablet's screen. This is based on observations in previous studies using touch-enabled devices (Goncu C. and Marriot K., 2011; Poppinga B. *et al.*, 2011) where experts found that the use of one finger was sufficient for vibro-tactile line tracing, and that little improvement (in exploration of haptic maps on a touch-screen) was shown when using multiple fingers simultaneously (Giudice N. A. *et al.*, 2002). Targets displayed on the tablet's touch-screen are referenced to a fixed coordinate system, which allows making specific and detailed measurements (e.g., touch position coordinates, finger path angles, etc., cf. Section 4) whenever an on-screen target is touched. Auditory output, which is only used to help the tester navigate from one experimental test to another (and not in identifying or tapping targets within *FittsEVAL*'s experimental tests), is delivered from the device's onboard speakers.

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[6] A developer and licensor of touch feedback (haptic) technology, https://www.immersion.com/
[7] Developed by Immersion Corporation, https://www2.immersion.com/developers/phocadownload/

Our current prototype system implements *FittsEVAL's* experimental protocol, including all experiments, phases, and steps, described in Section 3.2. Yet, note that it can be easily extended to allow additional functionality[8], and can be integrated and used with any off-the-shelf (Android) touch-screen device with an embedded vibration motor. (Tekli J. *et al.*, 2017)

3.2. Experimental Protocol

As for our *FittsEVAL* experimental protocol, it consists of three pointing task experiments (Figure 8) covering: i) Distance variation from target, ii) Size variation of target, and iii) Angle of approach variation w.r.t. the target. Note that in contrast with pointing task experiments conducted in previous studies, e.g., (Fitts P. M., 1954; Fitts P. M. and Peterson J. R., 1964; Sasangohar F. *et al.*, 2009; Soukoreff R. W. and MacKenzie S. I., 2004), users in this case cannot see the required target. Therefore, it is necessary to design a learning phase for the blind tester in order to give her/him the opportunity to identify the location of the targets before starting the experiment. As a result, each of the above experiments is divided into two phases: i) Identifying the target's location (learning phase), and ii) Tapping the target (actual test phase). Experiments are further described in the following sub-sections.

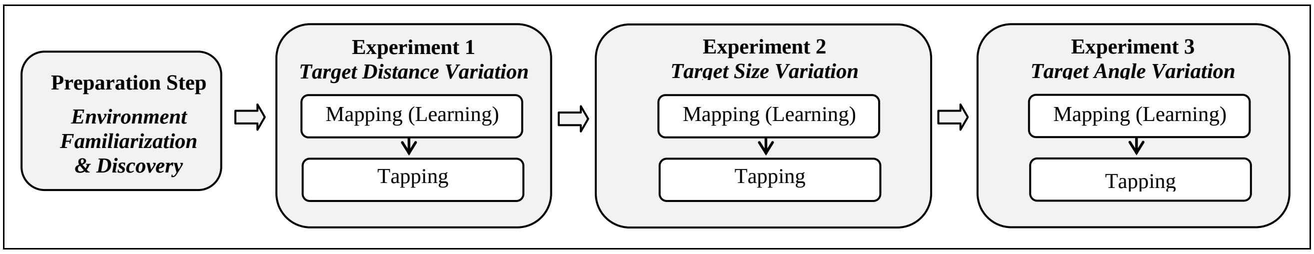

Figure 8. *FittsEVAL*'s experimental protocol organization.

Note that prior to executing the experiments, an *environment familiarization and discovery* step is required, in order to explain to each test candidate: the experiments to be conducted, the nature of each experiment, the tasks to be completed, as well as how to handle the vibrating touch-screen (prototypical) environment (e.g., how targets are presented on the vibrating screen, control buttons, etc.). In addition, test subject profile data (e.g., name, age, gender, type of blindness: since birth or after birth, etc.) are recorded at this stage.

3.2.1. Experimental Set-Up

Each test of each experiment in *FittsEVAL* is made of several pointing trials. Each of them consists in clicking on a *target point* (which we identify as C_t), going from a point of origin or *source point* (which we identify as C_s). For each pointing trial, the user must first locate and click on C_s. Then, when ready, she/he should let go of C_s and attempt to click on C_t, and then point back at C_s as quickly and as precisely as possible. Each pointing trial consists in touching the target point and going back to the source point, such that C_s and C_t switch roles halfway through each test (in pointing back: the target becomes the source and vice versa), as shown in Figure 9.

Following the recommendations of Soukoreff and MacKenzie (Soukoreff R. W. and MacKenzie S. I., 2004), adopted from the ISO9241-9 standard (ISO, 2002), pointing tasks need to be evaluated in all directions in order not to favor any particular movement. To achieve this, we represent both source and target points C_s and C_t as circular shapes (cf. Figure 9), preserving the same properties of C_s and C_t regardless of the tester's angle of approach when pointing between C_s and C_t.

- Experiment 1: Distance Variation From Target

The goal of this experiment is to prove the following hypothesis: *A pointing task performed by a blind user on a vibrating touch-screen is affected by the distance between the source and the target points following Fitts' Law*. To do so, we consider different distances separating C_s and C_t, ranging from 120, 200, to 240 pixels (on a 1280×800 screen resolution, with a 149 pixels-per-inch screen density, and 10.1 inch screen size, cf. Section 3.1). Distance values are chosen realistically: following existing Fitts' Law evaluations (Fitts P. M., 1954; Sasangohar F. *et al.*, 2009) (cf. Section 2) manually adapted to the size and resolution of our touch-screen[9]. Since our source and target points are represented as circles, distances here are measured between the corresponding circle centers. The size of C_s and C_t is fixed for each run of the Test 1 (considering the size values in Test 2), and their angle is fixed at 0° (i.e., 180°) such that they are placed horizontally on the *x* axis (cf. Figure 10).

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[8] We have extended our experimental prototype to perform simple contour-based image identification and recognition in (Tekli el al., 2017).

[9] Running our experiments on a different screen with a different size or resolution, or changing the screen resolution will require an adjustment or calibration step in order to adjust shape distances and sizes accordingly. This will be further investigated in a future work.

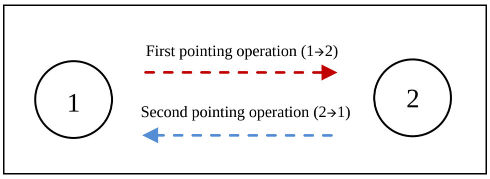


Figure 9. A pointing trial in *FittsEVAL*.

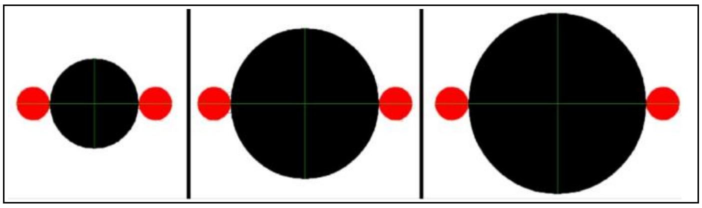


Figure 10. Prototype snapshots showing sample size variations (40, 60, and 80 pixels respectively) of source and target (red circles).

- **Experiment 2:** Size Variation of Target

The goal of this experiment is to prove the following hypothesis: *A pointing task performed by a blind user on a vibrating touch-screen is affected by the size of the source and the target points following Fitts' Law*. To do so, we consider different sizes of C_s and C_t, ranging from 40, 60, 80, to 90 pixels (given the same screen resolution, density, and size configurations mentioned above). Size values were also chosen realistically (similarly to varying distances), following existing Fitts' Law evaluations adapted to the size of our touch-screen. Since our source and target points are represented as circles, size here stands for circle diameter. The distance between C_s and C_t is fixed for each run of Test 2 (considering the distance values of Test 1), and their angle is fixed at 0° (i.e., 180°) such that they are placed horizontally on the *x* axis (cf. Figure 11).

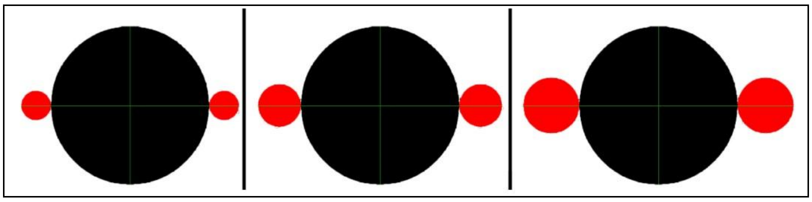


Figure 11. Prototype snapshots showing sample size variations (40, 60, and 80 pixels respectively) of source and target (red circles).

- **Experiment 3:** Angle Variation of Target

The goal of this experiment is to prove the following hypothesis: *A pointing task performed by a blind user on a vibrating touch-screen is <u>not</u> affected by the angle between the source and the target points, following Fitts' Law*. To do so, we consider different angle variations of C_s and C_t, from 0, 30, 60, 90, 120, to 150 degrees (representing opposite angles for the same trial, cf. Table 1). Angle values were chosen sensibly (similarly to distance and size variations in the previous experiments), with a fixed difference of 30 degrees, as a realistic variation which can be detected by testers[10]. The distance between C_s and C_t is fixed to 120 pixels, and their size is fixed to 40 pixels (given the aforementioned screen resolution, density, and size, cf. Figure 12)[11].

Table 1. Angles to the center of the shapes w.r.t. the *x* axis

Test	0	1	2	3	4	5
Angle from C_s to C_t	-150	-120	-90	-60	-30	0
Angle from C_t to C_s	30	60	90	120	150	180

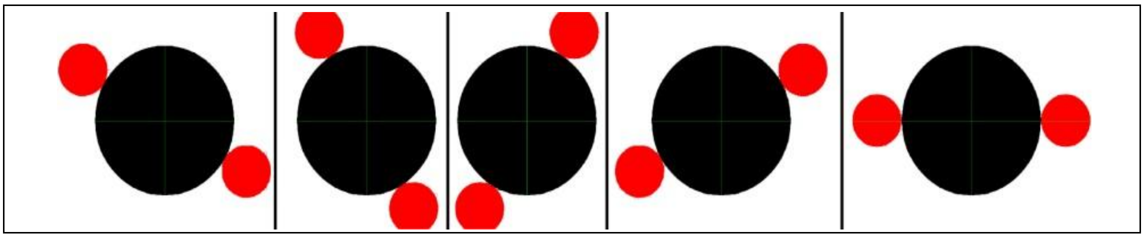


Figure 12. Prototype snapshot showing sample angle variations (30, 60, 120, 150, 180 respectively) between source and target (red circles).

[10] Varying the difference between angles would make the pointing task even more challenging for testers, which we report to a future study.

[11] An extension of Experiment 3 where we consider angle variations for different combinations of distance (*A*) and size (*W*) will be considered in an upcoming dedicated study.

3.2.2. Learning and Testing Phases in each Experiment

Each of the above experiments is divided in two main phases: i) a learning phase, and ii) a testing phase, aiming to confirm/reject the experiment's main hypothesis.

- Phase 1: Learning - Identifying the Target's Locations

The objective of this phase is to test if a blind person is capable of locating source and target points presented as circular Plexiglas shapes of 0.5 mm in thickness (following standard embossed paper thickness (SOCRATE-COMENIUS, 2000)), and their counterparts presented on a vibrating touch-screen. It is also considered as a learning phase, providing the *tester* with the correct source and target point locations, so that she/he can learn them on the vibrating screen. The experiment is conducted as follows:

i. Presenting to the *tester* each of the source and target configurations (following distance, size, or angle variations, depending on the experiment at hand), in-order, by superimposing the Plexiglas on the corresponding locations on the touch-screen,
ii. Presenting to the *tester* each of the source and target configurations, in-order (i.e., same order as above), on the vibrating touch-screen (without the Plexiglas shapes), and checking if she/he is able to locate the target, and then point back to the source. The coordinator helps locate the tester's finger for the first touch on-screen, by pointing it on the source object.
iii. Following each trial, the *coordinator* speaks with the *tester* to explain whether she/he is far away or near to the desired locations (e.g., "*move a little bit to the right*") to help her/him locate the points correctly. The tester is not allowed to tap neither points in order not to practice,
iv. The procedure is repeated until the *tester* is capable of positively locating source and target points on the vibrating touch-screen, w.r.t. their Plexiglas counterparts.

The number of mistrials and times the tester correctly identifies target/source locations, as well as the time (between pressure of touch on C_s and C_t) per test, among other parameters, are stored and analyzed later (in order to study and compare the perceived difficulty levels and training times required by different test candidates). This is repeated for each and every phase in each experiment.

- Phase 2: Testing - Tapping the Target

The objective of this phase is to test if a blind person can tap the desired targets presented on a vibrating touch-screen, only by helping her/him locate the starting (source) point. The tester is instructed to accomplish the pointing tasks by moving the lower arm while only using the index finger. The experiment is conducted as follows:

i. The coordinator locates the tester's index finger on the source point C_s provided on the touch-screen.
ii. The coordinator asks the tester to tap as fast as possible the target C_t and then point back at C_s, as quickly and as accurately as possible, until she/he hears the sound: "*Next*", as an auditory output produced by the tablet's speakers[12], announcing the end of the session and the beginning of a new one.

Accuracy in finger tapping consists in correctly pointing from the source to the target and vice versa, and is evaluated by measuring the percentage of tapping errors (which occur every time the user misses the target), as further described in the following section. Even though the tester cannot actually see the source and target points, she/he is not allowed to search for them in this phase (given the training and preparation the tester went through in the previous phase of the experiment).

4. Experimental Evaluation

We conducted experiments on sighted and blind candidates to test the feasibility of our proposal. Twenty-nine testers, aged between 21 and 30 years old, participated in the experimental evaluation: i) six Blind Since Birth (i.e., BSB) testers (1 female and 5 male), ii) seven Blind After Birth (i.e., BAB) testers (5 females and 2 males), and iii) sixteen Sighted (8 females and 8 males). We asked half of our sighted testers (4 females and 4 males) to conduct the experiments Blindfolded (i.e. BF), whereas the other half conducted the experiments sighted (so that we could compare and contrast results). BSB and BAB testers were student volunteers from the Lebanese School for the Blind and Deaf [13], while BF and Sighted testers were undergraduate and graduate students as well as faculty who volunteered from the authors' educational institutions (cf. Figure 13). The tests were coordinated by the authors and their research assistants. We have recorded various experimental measurements in order to analyze and evaluate the results obtained with each experiment, including, for each pointing trial: i) the size of the target to be reached, ii) the distance from the source (circle)'s center to the target's center, iii) the angle of approach to get to the center of the target, iv) the coordinates of the touch position, v) the coordinates where the touch was released, vi) the time taken while still pressing, vii) the time between two clicks, as well as viii) the time between two correct clicks. In the following, we first present the results obtained

[12] Other basic auditory messages are generated by the prototype system, namely: *"Begin Experiment"* and *"End of Experiment"*. These are simply provided to help the user navigate the experimental phases, and do not affect or interfere with the pointing tasks.
[13] http://www.lsbdbaabda.com/about.php

when varying pointing *distance* and *size* (which are central parameters following Fitts' Law), and then discuss the results obtained when varying pointing *angles*, and their impact on the pointing task. A recap of the experimental results is provided in Section 4.3.

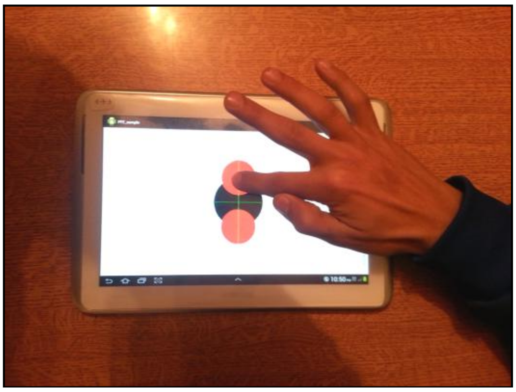


Figure 13. Snapshot of a tester's hand using the prototype.

4.1. Experiments 1 and 2: Distance and Size Variations

Following Experiment 1 (*distance variation*)'s learning phase, each tester completed 3 experimental sessions for each of the 3 distance configurations (i.e., 120, 200, and 240 pixels), each session consisting of 25 pointing trials. For BSB, BAB, and BF testers, distance variations were presented in-order (as they were explored in the learning phase[14]), whereas they were presented randomly for sighted testers. Also, sighted testers did not undertake the learning phase (designed specifically for blind/blindfolded candidates). Experiment 1 was repeatedly executed in 4 consecutive runs, each run with a different target size (i.e., 40, 60, 80, and 90 pixels). The same process was undertaken with Experiment 2 (*size variation*). Each trial (in both Experiments 1 and 2) lasted between 50-and-90 seconds, each test run lasted almost 3-5 minutes, and both Experiments 1 and 2 as a whole lasted almost 12-15 minutes. Participants could take breaks between trials/runs. All in all, each tester performed: 4 (runs of Experiment 1) × 3 (distance variations) × 25 (pointing trials) + 3 (runs of Experiment 2) × 4 (size variations) × 25 (pointing trials) = 600 pointing trials.

Table 2 presents the index of difficulty (*ID*) values obtained following Fitts' model for the different distance (*A*) and size (*W*) variations. Figure 14 and Figure 15 present the average movement time (*MT*) and the average percentage of tapping errors (*Err*) obtained with the different groups of testers, corresponding to the variations of distance and size in Table 2. A tapping error occurs every time the user misses the target in a pointing trial, such that a higher percentage of tapping errors indicates lower accuracy in performing the pointing task. The angle of attack in Experiments 1 and 2 is fixed at 0° (i.e., 180°).

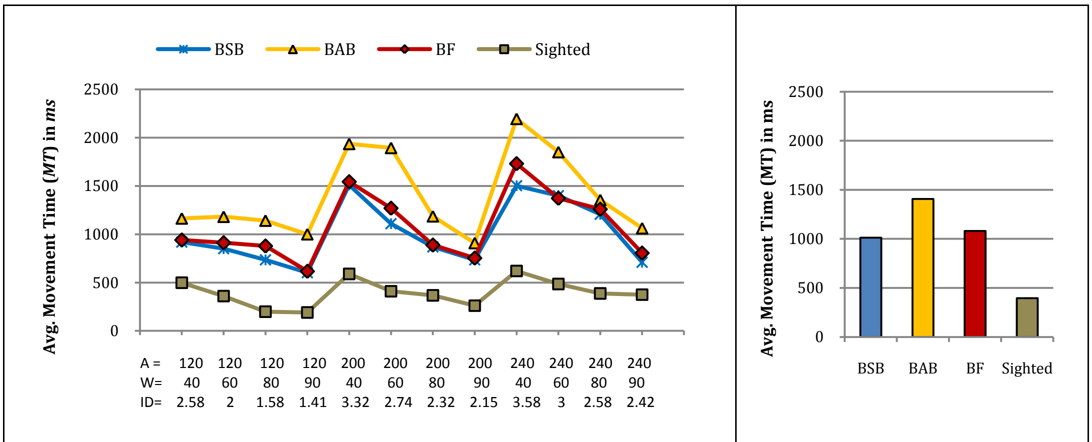
Table 2. Index of difficulty (*ID* in *bits*) obtained following Fitts' model for different target sizes (*W*) and distances (*A*).

W \ A	120	200	240
40	2.5849	3.3219	3.5849
60	2	2.7369	3
80	1.5849	2.3219	2.5849
90	1.4150	2.1520	2.4150

Following Figure 14.a, one can realize that participants spend more time in aiming at small and far away targets (higher average *MT* scores were obtained with low *W* and high *A* values) compared with lesser time spent on aiming at bigger and closer targets (lower average *MT* scores were obtained with high *W* and low *A* values). This is specifically visible by looking at the peak and bottom points in the *MT* graphs of Figure 14.a were *W*=40 (smallest size) and *A*=240 (highest distance/amplitude) produce the highest *MT* scores, whereas *W* = 90 (biggest size) and *A* = 120 (lowest distance) produce the lowest *MT* scores. This concurs with *ID* scores shown in Table 2 which are computed following Fitts' Law (cf. Formula 1 in Section 2). Also, results in Figure 14.a highlight clear patterns with target size (*W*) and distance (*A*) values, where *MT* tends to increase with *A* and decreases with *W*. These effects concur with Fitts' Law, and have been documented in related studies, e.g., (MacKenzie I.S., 1992; Sasangohar F. *et al.*, 2009; Soukoreff R. W. and MacKenzie S. I., 2004).

[14] Distance and/or size variations could not be presented randomly since testers could not see the targets. Hence, we relied instead on their training and in-order memorization of the configurations in the learning phase.

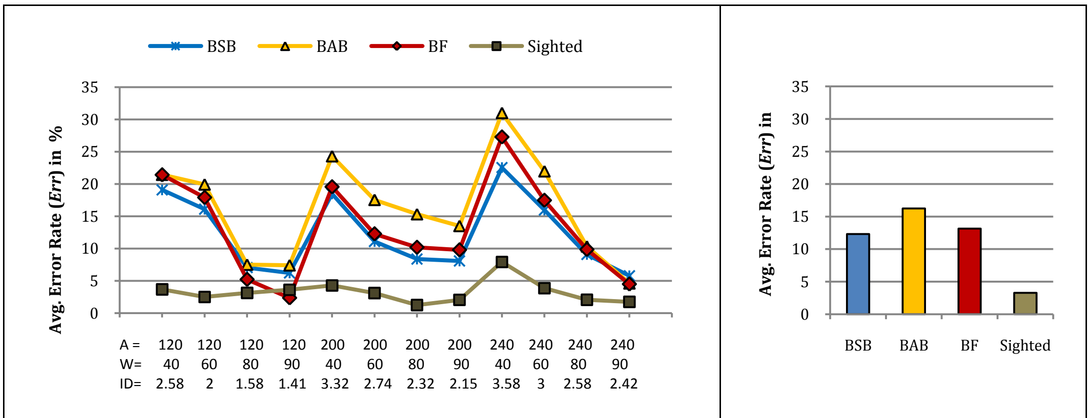
However, it is also clear that *MT* differs significantly between BSB, BAB, and BF testers on one hand, and sighted testers on the other hand, with sighted testers completing pointing tasks significantly (almost three times) faster than the others. The highest *MT* levels are generally achieved by BAB testers, ranging from 909 ms to 2195 *ms* (with $mean(MT_{BAB})$ = 1406.38 *ms*), followed by BF testers with *MT* ranging between 617 *ms* to 1731 *ms* (with $mean(MT_{Blindfolded})$ =1081.42 *ms*), then BSB testers with *MT* ranging between 602 *ms* to 1502 *ms* (with $mean(MT_{BSB})$ = 1012.62 *ms*), compared with 190 *ms* to 620 *ms* with sighted testers (with $mean(MT_{Sighted})$= 395.34 *ms*).



a. Average *MT* per *ID* value[15] | **b.** Mean *MT* per tester group

Figure 14. Plotting movement time (*MT*) of blind, blindfolded, and sighted testers, against Fitts' index of difficulty (*ID*).

By analyzing pointing error rates, one can realize that *Err* values are generally high with small targets (with *Err* > 18% with the smallest *W*=40), and reaching the highest *Err*=25.48% with the most distant (*A*=240) target. In addition, the error rates obtained with BSB, BAB, and BF testers are significantly (almost 4 times) higher than those obtained with sighted testers for small and distant targets. *Err* levels are generally highest with BAB testers, ranging from 4.62% to 31.01% (with $mean(Err_{BAB})$=16.25%), followed by BF testers with *Err* ranging from 3.80% to 25.48% (with $mean(Err_{BF})$=13.61%), then BSB testers with *Err* between 5.78% and 22.55% (with $mean(Err_{BSB})$ = 12.32%), compared with only 1.75% to 7.93% with sighted testers (with $mean(MT_{Sighted})$= 3.28%).



a. Average *Err* per *ID* value | **b.** Mean *Err* per tester group

Figure 15. Plotting tapping error rates (*Err*) of blindfolded and sighted testers, against Fitts' index of difficulty (*ID*).

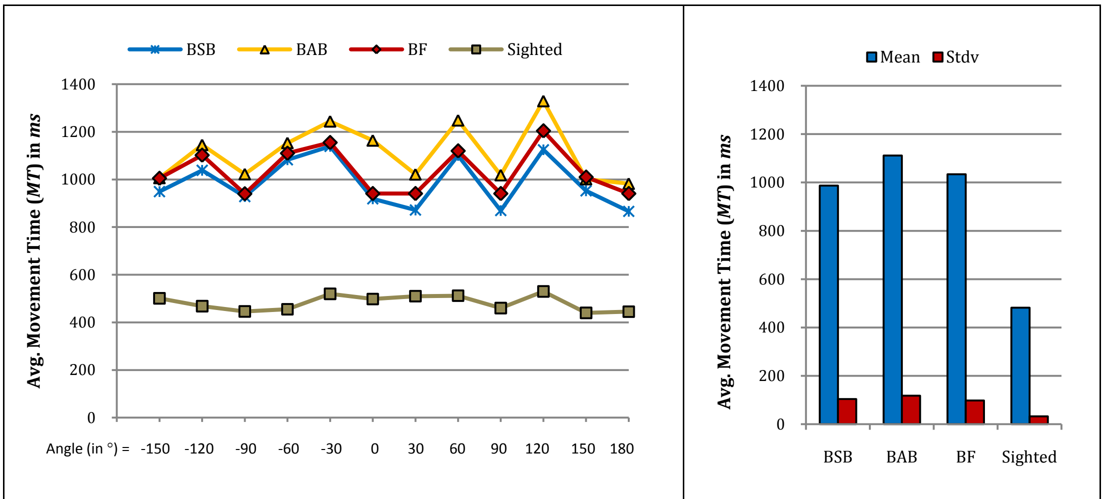
[15] Note that *MT* values shown in the graph are discrete and unrelated: each corresponds to a combination of distance (*A*) and size (*W*) values as shown on the *x* axis' labels. However, we show *MT* values in the form of continuous plots in order to highlight their variation: how they increase/decrease with increasing/decreasing *A* and *W* values (e.g., the obtained *MT* results in Figure 14.a follow typical Fitts' Law behavior). The same goes for *Err* values in subsequent graphs.

To sum up, results show that selecting small and far-away targets seems challenging for touch-based interaction with blind (and blindfolded) testers. Yet, results generally concur with Fitts' Law, which seems to accurately apply for blind users executing the pointing task on a vibrating touch-screen: considering target size and distance variations with a fixed angle of approach.

4.2. Experiment 3: Angle Variations

Following Experiment 3 (*angle variation*)'s learning phase, each tester completed 6 experimental sessions for each of the 6 angle configurations (from 30° to 180°), each session consisting of 25 pointing trials. For BSB, BAB, and BF testers, angle variations were presented in-order (as they were explored in the learning phase), whereas they were presented randomly for sighted testers. Also, sighted testers did not undertake the learning phase (designed specifically for blind/blindfolded candidates). In this test, we considered a fixed target distance (A=120) and target size (W=40), while only varying the target's angle[16].

Results in Figure 16 show a small variation in movement time when varying the angle of attack with BSB, BAB, and BF testers, and an even smaller variation with sighted testers. The highest MT variation levels are achieved with BAB testers with $stdv(MT_{BAB})$=118.41*ms* (and $mean(MT_{BAB})$=1111.51*ms*), followed by BSB testers with $stdv(MT_{BSB})$=104.14*ms* (and $mean(MT_{BSB})$=986.79*ms*), and then BF testers with $stdv(MT_{BF})$= 98.25*ms* (and $mean(MT_{BF})$ =1034.17*ms*), compared with a significantly lower (almost 3 times lesser) *MT* variation levels with sighted testers with $stdv(MT_{Sighted})$= 32.49*ms* (and $mean(MT_{Sighted})$=480.58*ms*). This tends to concur with Fitts' model where *MT* is (almost) not (or only marginally) affected by the angle of approach to the target.



a. Average *MT* per angle of attack

b. Mean and standard deviation levels of *MT* per tester group

Figure 16. Average movement time (*MT*) for each angle variation, with blindfolded and sighted testers

However, results in Figure 17 show that varying the angle of attack seems to have a serious impact on the pointing error rate. Results in Figure 17.a show that BSB, BAB, and BF testers were able to locate and tap straight targets more easily than ones with steep angles. That is to say, targets presented with angles 90°,-90°, 0° and 180° were relatively quickly learned and easily tapped by BSB, BAB, and BF testers (resulting in minimal average tapping error percentages varying from average 4% with 90° to 20% with 180° in Figure 16), compared with angles 120°, -60°, and -30° for instance, producing 33%, 40%, and 62% average tapping error rates respectively. Figure 17.b shows that BAB testers produce the highest average error rates of 26.06%, followed by BF testers with average 20.37%, then BSB with average 18.22%, compared with an (almost 5 times lesser) average 5.05% error rate with sighted testers. In other words, results show that the pointing error rate does not seem to be seriously affected (only varies slightly, and does not appear to follow any specific pattern) when varying angles with sighted testers. Based on the latter results, we can state that the pointing task performed by blind (and blindfolded) users on a vibrating touch-screen seems to be affected by the angle of attack between the source and target points, which does not concur with Fitts' Law.

Note that a dedicated future study is required in order to further investigate the impact of angle variation on *MT* and *Err* for blind users utilizing a touch-screen, in order to (possibly) suggest an adaptation of Fitts' Law which could better model the pointing task in this context. Here, the angle of approach might need to be considered as a possible additional parameter in the equation to calculate the index of difficulty (*ID*) and movement time (*MT*) of a pointing task.

[16] Extending this experiment to consider angle variations for different combinations of distance (A) and size (W) will be considered in a dedicated upcoming study.

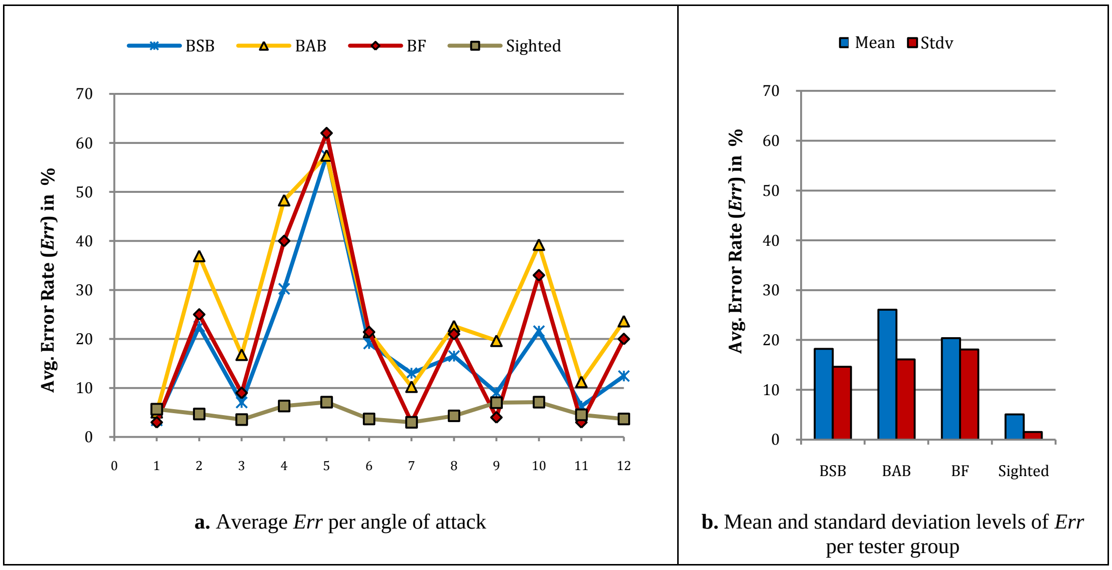


Figure 17. Average tapping error rate (*Err*) for each angle variation, with blindfolded and testers.

4.3. Recap of Experimental Results

To sum up, we short-list our observations in Experiments 1, 2, and 3 as follows:

- Results of Experiments 1 and 2 show that *MT* (movement time) and *Err* (tapping error percentage) for all groups of users tend to concur with Fitts' Law, where both average *MT* and *Err* increase with increasing target distance (1) and decreasing target size (2). In other words, both hypotheses of Experiments 1 and 2 have been verified.
- Results of Experiments 1 and 2 also show that BAB testers produce the highest *MT* and *Err* levels, followed by BF testers and then BSB testers.
- Results of Experiment 3 show that *MT* only marginally varies with varying angles of the target, which concurs with Fitt's Law: given that angle variation is not a parameter in Fitt's mathematical model.
- Yet, results of Experiment 3 show that average *Err* levels are seriously affected by changes in the angle of the target, where *Err* is highest with steep angles (e.g., 120° and 60°), and lowest with close to flat (e.g., 0°) angles. *Err* is highest with BAB testers, followed by BF and then BSB. Given the latter, we can state that Experiment 3's hypothesis is not verified: *A pointing task performed by a blind user on a vibrating touch-screen seems to be affected by the angle between the source and target points.*

5. Conclusion

In this paper, we evaluate whether Fitts' Law can be applied for blind candidates using the vibration modality on a touch-screen. In contrast with all previous pointing task experiments, users in this case cannot see the required target. To achieve this, we designed an experimental framework titled *FittsEVAL* studying the ability of blind users to tap circular shapes on a touch-screen considering different variations of the target's distance, size, and angle of approach. Experiments on (sighted and) blindfolded candidates show two observations: i) Fitts' Law can be effectively applied for blind users when varying target size and distance on the touch-screen, ii) Fitts' Law does not seem to be applicable when varying the angle of approach to the target.

We are currently conducting additional experiments with different touch-screen resolutions and sizes (e.g., same size targets might be perceived differently on different screen sizes), aiming to specifically study the effect of angle variation on the pointing task. Integrating auditory cues along with vibration feedback seems specifically promising in this context, providing blind testers with direction indications to help them handle angle variations. Here, it would be useful to utilize the PRISMA[17] checklist model (Moher D. *et al.*, 2009) to perform a critical and systematic appraisal of the effect of different modalities on the pointing task. To further generalize the results, it would also be interesting to develop adapted usability questionnaires based on the System Usability Scale (SUS) by (Brooke J., 1996), quantifying the testers' effectiveness, efficiency, and satisfaction levels in performing the different pointing tasks, considering different parameter variations and different modalities. The following step will be to evaluate a blind user's capability of distinguishing and recognizing spatial relations between simple geometric objects presented on a vibrating touch-screen, namely directional (e.g., *top-of*, *left-of*, etc.), metric (e.g., *far*, *near*, etc.), as well as topological relations (e.g., *disjoint*, *adjacent-to*, etc.) (Tekli J. *et al.*, 2017). We also plan to evaluate a blind user's ability to track trajectories

[17] Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

presented as a discrete set of points or as a continuous line on-screen, which is central in various applications ranging over navigating 2D indoor layouts (Su J. *et al.*, 2010) as well as accessing software and Web-based graphical user interfaces (i.e., GUIs) (Bou Issa Y. *et al.*, 2010; Bou Issa Y. *et al.*, 2009). Here, it would be interesting to evaluate the accuracy of the tester's first touch on-screen, before jumpstarting the pointing or the trajectory tracking tasks. In the long run, we plan to evaluate a blind tester's ability to follow moving targets presented on a touch-screen. While existing studies in this area have mostly focused on sighted testers utilizing a mouse, a joystick, or a helmet-mounted sight to manage a cursor present on a screen display, yet to our knowledge, no existing approach has evaluated a blind tester's ability to follow (with his/her finger) a moving target presented on a touch-screen: utilizing vibration (only) modality (i.e., without the help of sound or audio cues). Here, we remind that a major problem with vibrating touch-screen technology is that the vibration feedback involves the entire device (i.e., the whole device vibrates, not the point of contact with the tester's fingertip), which naturally impedes the whole accessibility process, including trajectory and motion detection. Yet, a new technology that could overcome this limitation is offered by Tesla Touch (Bau O. *et al.*, 2010), using the principle of electro-vibration that produces a dynamic friction between the fingertip and the screen's surface resulting in a localized haptic feedback. Thus, investigating next generation touch-screen prototypes based on localized electro-vibration technology, while integrating different modalities (such as sound, human speech, and thermal display (Hribar V. E. and Pawluk D. T. V., 2011)) to provide a full-fledged visual data accessibility solution for blind users remains our strategic goal.

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