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CHARACTERIZING HABITUATION USING THE TIME-ON-TASK METRIC IN AN IRIS RECOGNITION SYSTEM

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CHARACTERIZING HABITUATION USING THE TIME-ON-TASK METRIC IN AN IRIS RECOGNITION SYSTEM

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To my parents and brothers: This is for always providing me love and support and for always believing in me.

To my friends and colleagues: This is for never doubting me, even when it was easy for me to.

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ABSTRACT

Hasselgren, Jacob A. M.S., Purdue University, May 2014. Characterizing Habituation Using the Time-on-task Metric in an Iris Recognition System. Major Professor: Stephen J. Elliott.

This thesis presents a characterization of biometric habituation in an iris recognition study using qualitative analysis of a distributed habituation survey and quantitative analysis of iris images collected in 2010 and 2012. The performed analyses answered the following two questions: a) How consistently does the biometric community define habituation?; and b) Does the time-on-task variable provide enough evidence to indicate the existence of habituation in an iris recognition system? The qualitative analysis examined responses to 12 habituation-related questions from 13 biometric experts to identify common themes that not only determined definition consistency but also characterized critical components often omitted from habituation definitions. Upon completion of the survey analysis, this study concluded that while aspects of habituation were universally understood, habituation in its entirety was not. The quantitative analysis examined trends in mean time-on-task using number of visits as a covariate. Subjects repeatedly (20 captures per visit and 25 maximum attempts per visit) interacted with an iris recognition camera, returning for at least eight visits. The trends in the resulting time-on-task, image quality and matching performance indicated that habituation effects were identifiable near the end of the 2012 collection.

CHAPTER 1. INTRODUCTION

A subconscious learning process occurs when a person interacts with a physical device. Depending on factors such as device design and subject demographics, this learning may or may not result in the intended interaction with the device. This question of interaction is particularly applicable to biometric systems because users typically follow a defined set of instructions to successfully capture their biometric information. Not acknowledging this inevitable process in the design and implementation of biometric systems can influence a device's performance in ways ranging from subtle anomalies to complete system failure. This process of sub-conscious learning is the core component of habituation.

Due to its complex nature, a generalized definition of habituation may not be effective in evaluating specific applications of biometric devices. A valid examination requires consideration of modality, application and the specific device. Despite the biometric community's success at developing methods of evaluating and defining habituation, the current available literature does not comprehensively consider the broad range of biometric devices used for identification. The limited and varying number of definitions of habituation can be found in standard documents (ISO/IEC JTC1 SC37, 2005) and research papers (Theofanos, M., Micheals, R., Scholtz, J., Morse, E., & May, P., 2006; Kukula, E., Elliott, S., Gresock, B., & Dunning, N., 2007), the latter of which focus particularly on the fingerprint and hand geometry modalities. However, no research exists on the habituation in an iris recognition system. Iris recognition is an established modality that has shown to be a reliable identifier (National Science and Technology Council, 2006). Habituation is particularly applicable in an iris recognition system because this technology has been deployed at international borders with a wide distribution of subject use frequency. In operational environments, biometric systems must be capable of providing a certain level of throughput and must remain technologically current, or they will not be adopted (Millward, 2012; UK Border Agency, 2014). Understanding the significant aspects of habituation within a biometric system enables targeted design improvements that assist in achieving the required level of throughput. However, the existing definitions of habituation are not consistent in the literature (Elliott, 2004; Theofanos et al., 2006; Kukula et al., 2007; Tamer et al., 2009). This thesis does not claim that these definitions are incorrect, but a disparity was observed in the metrics and terminology used to develop them. These observations formed the basis of a hypothesis stating that habituation is not universally understood among the community of biometric experts.

A second hypothesis was also formed after reviewing Theofanos et al. (2006) and Kukula et al. (2007), who examine image quality and matching performance as indicators of habituation, stating that the elapsed time between the initial device contact and capture completion, or the metric referred to as "time-on-task" in this thesis, was a better gauge of habituation in both laboratory and operational environments.

A mixed-methods study was conducted to understand habituation in an iris recognition system. Both a qualitative analysis of a habituation survey and a quantitative analysis of two iris data collections were performed for this thesis. First, a habituation survey was distributed among the expert community to understand the initial definitions of biometric habituation. This survey served a dual purpose. Not only did it show that the perception of habituation was inconsistent throughout the biometric community but that it was also used to determine if biometric experts viewed time-on-task as a valid indicator of habituation. Prior to the proposal in this thesis, it was hypothesized that the time needed to capture an iris image, as a function of the time-on-task metric, was a more efficient way of identifying habituation. Therefore, a quantitative analysis of the time needed to capture was performed on an iris data collection effort that occurred in 2012.

Supplemental analysis was also completed on matching performance and image quality as gauges of habituation. This analysis not only allowed for the comparison of time-on-task to matching performance and image quality but also allowed the iris data from a previous 2010 study to be used to determine if habituation occurred between different studies.

1.1 Statement of the Problem

References to habituation exist in multiple biometric research papers (M1.5, 2003; Theofanos et al., 2006; Kukula et al., 2007), but only a limited set of literature explicitly identifies variables that effectively describe the existence of habituation in a biometric system. Additionally, as these sources do not all examine the same modality, disparities in the metric identification and terminology of the definitions can be noted.

The literature also states that the effects of habituation may differ from one modality to the next (M1.5, 2003). After an extensive search of the available literature, a consistent and effective definition was concluded to be absent in the literature on iris recognition.

1.2 Significance of the Problem

Social science literature defines habituation as a decrease in a response to a stimulus (Rankin, Abrams, Barry, Bhatnagar, Clayton, Colombo, Coppola, Geyer, Glanzman, Marsland, McSweeney, Wilson, Wu, & Thompson, 2009). During the implementation of a biometric device, the stimulus can be a prompt from either the device itself or a device operator notifying the user that the capture has begun. The resulting response from the user is any action required to complete a capture, whether it concludes in a success or a failure. In this context, a decrease in the time needed by the user to complete a capture signifies habituation.

To implement an iris recognition system in an operational environment, an unhabituated user may cause a greater number of errors or require more time to successfully allow identification by the device. In high-volume environments, such as an airport, these problems can cause bottlenecks and decrease throughput (Millward, 2012). Iris recognition devices have been implemented in operational environments, such as airports, where security and throughput have top priority. These iris recognition devices, which had been designed to increase throughput, actually caused throughput to decrease because of the users' inability to interact with the devices properly (Millward, 2012).

The significance of this study lies in providing integrators with qualitative and quantitative data analyses that suggest the existence of habituation in an iris system for use in future operational settings.

1.3 Scope

Previous studies describing habituation in a biometric system concentrate on the metrics of performance and quality (Theofanos et al., 2006; Kukula et al., 2007). In these two references, image quality is shown to improve with the number of attempts required. However, these research studies consider only fingerprint recognition and hand geometry modalities. Habituation in the modality of iris recognition has yet to be observed and published. Therefore, the scope of this thesis was to define habituation in an iris recognition system. Moreover, a habituation survey was distributed to biometric experts, prior to quantitative analysis, to determine if habituation was universally defined, with the secondary purpose of verifying the practicality of using time-on-task as a metric to demonstrate habituation's existence.

As noted above, Kukula et al. (2007) and Theofanos et al. (2006) studied hand geometry and fingerprint recognition, respectively, and measured performance, number of attempts, and the quality of collected biometric samples. This thesis, however, attempted to define habituation by analyzing the time-on-task variable of a data collection that occurred over eight visits from July 2012 – June 2013. Time-on-task was derived from process logs internal to the iris camera used for the study that recorded each capture attempt that occurred throughout the data collection period.

Matching performance and image quality were also examined to supplement the time-on-task analysis and utilized iris images from the 2012 data collection exercise. Furthermore, images that were available from a previous iris data collection effort in 2010 were also analyzed because some individuals from the 2010 study also participated in the 2012 exercise.

A habituation survey was given to experts in the biometric community prior to analyzing time-on-task. The results of the habituation survey also served as a means of showing that the perceptions of habituation among the biometric community were inconsistent.

1.4 Statement of Purpose

The purpose of this study was to examine current definitions of habituation through the examination of an iris recognition system and based on a literature review and responses received for a given survey. Additionally, this thesis sought to validate these definitions of habituation using collected data and statistical analysis of the time-on-task metric.

1.5 Research Questions

This study attempted to answer two research questions: a) How consistently does the biometric community define habituation?; and b) Does the time-on-task variable provide enough evidence to imply the existence of habituation in an iris recognition system?

1.6 Assumptions

The assumptions for this study were as follows.

1. The number of subjects sampled for this study was sufficient to validate the definition given in this thesis.

2. Each subject attempted to successfully provide at least 20 presentations per visit over eight visits during the 2012 data collection.

3. With the exception of contact lenses, no head or eyewear was worn during collection presentations.

4. The responses to the habituation survey received by biometric experts were honest.

1.7 Delimitations

This study was delimited in the following ways:

1. Data were collected only in the MGL laboratory at the West Lafayette, Indiana campus of Purdue University

2. Three devices from only one iris device manufacturer, Aoptix Technologies, were used during the study.

3. The only type of iris device examined in the study was a stand-off iris camera. Other types of iris cameras, such as mobile and fixed-field, were not included in this study.

4. Only subjects who completed all eight visits were considered in the analysis.

5. Ethnicity was not considered when the population was sampled, although it was reported.

6. Gender was not considered when the population was sampled, although it was reported.

7. Age was not considered when the population was sampled, although it was reported.

8. Only 25 attempts were allowed for each participant to submit 20 successful captures.

1.8 Limitations

This study was limited in the following way:

1. The study was limited to the time schedule of the overarching aging study employed by the researcher.

1.9 Definition of Key Terms

Acclimation: the "process in which a user of a biometric system adapts his or her techniques to achieve a proper match of his or her biometric template" (Kukula et al., 2007, p. 242).

Biometric decision time: is "the time required by the biometric subsystem to generate an accept or reject response based on the comparison score and the decision logic" (Elliott, Kukula, & Lazarick, 2009, p. 1023).

Dishabituation: is “the restoration of a habituated response by extraneous stimulation” (Thompson, 2009, p. 127); is “the actual removal or elimination of the process of habituation” (Thompson, 2009, p. 128).

Full habituation: This “occurs when a user matches his or her biometric template using subconscious techniques” (Kukula et al., 2007, p. 242).

Habituation: is “the behavioral response decrement that results from repeated stimulation and that does not involve sensory adaptation/sensory fatigue or motor fatigue” (Rankin et al., 2009, p. 136); is “the continued use of a biometric device” (Kukula et al., 2007, p. 242).

Iris: is “the muscle within the eye that regulates the size of the pupil, controlling the amount of light that enters the eye” (National Science and Technology Council, 2006, p. 1).

Iris recognition: is “the process of recognizing a person by analyzing the random pattern of the iris” (National Science and Technology Council, 2006, p. 1).

Partial habituation: is “the period of time during which no new adaptation techniques are used to achieve a successful match to the biometric template” (Kukula et al., 2007, p. 242).

Presentation: is “a submission of a single biometric sample on the part of a user” (ISO/IEC JTC1 SC37 Working Group 1, 2005, p. 3).

Sample: is “a user’s biometric measures as output by the data collection subsystem” (ISO/IEC JTC1 SC37 Working Group 1, 2005, p. 3).

Subject interaction time: “commences when a claim of identity is made (or presented), that is, swiping a card or entering a PIN by the user. The time ends when the individual has presented his/her biometric characteristic(s) and the sensor begins to acquire the sample." (Elliott et al., 2009, p. 1023).

Biometric subsystem processing time: is "the time taken for the system to acquire the biometric sample, to evaluate the quality of the sample, and to process that sample for comparison, if the quality is satisfied" (Elliott et al., 2009, p. 1023).

Template: is "a user's stored reference measure based on features extracted from enrollment samples" (ISO/IEC JTC1 SC37 Working Group 1, 2005, p.3).

Total transaction time: is "a sum of all the subcomponent periods of time associated with the biometric application system." (Elliott et al., 2009, p. 1023).

User: is "a person presenting biometric sample to the system" (ISO/IEC JTC1 SC37 Working Group 1, 2005, p.3).

1.10 Summary

Due to the lack of literature directly examining habituation in iris recognition, this thesis attempted to further study the topic. The problem with habituation in biometric systems can be observed in operational environments with low throughput rates and can be attributed to a user's inability to use the device.

To answer the proposed research questions, a habituation survey was given to a select number of biometric experts to determine if current definitions of habituation were universally accepted. Based on of the results of this survey, the time-on-task variable was verified as being capable of suggesting the existence of habituation in a given biometric system, with analyses of matching performance and image quality included to supplement time-on-task.

These variables formed the basis of a quantitative analysis of the data collected for an aging study conducted in the BSPA Labs during the summer of 2012 and continuing through the summer of 2013. The matching performance and image quality analyses examined the same aging study, but they also examined a similar iris study conducted with the same device in 2010. In particular, subjects who had participated in both studies were used to observe trends between the studies. The results of the habituation survey and quantitative analysis were compared to verify that the results of the quantitative analysis matched the perspectives of the biometric community.

CHAPTER 2. REVIEW OF LITERATURE

Prior to the formation of the hypothesis stating that habituation is not a universally defined term in the biometric community, the concept of habituation was discussed in the BSPA Labs, specifically during a video analysis of the human factors captured in iris data collection that occurred in 2010; the same study included in the analysis of matching performance and image quality. This discussion prompted an extensive review of the literature that explicitly defined, or even mentioned, habituation in both the biometric and social science contexts. However, before a review of habituation could be performed, a comprehensive review of biometrics and iris recognition was required to properly determine the methods of understanding habituation in the context of an iris system.

The review of literature was divided into six sections: an introduction to biometrics, iris recognition, principles of performance, an introduction to habituation, industry drivers and previous work related to this study.

2.1 Introduction to Biometrics

Biometrics is a method of authenticating an individual. This type of authentication is defined as "the automatic recognition of an individual based off of a physiological or behavioral characteristic" (Jain et al., 2002; National Research Council, 2011, p. 1).

Using biometrics for authentication differs from using other methods of authentication because it is “something you are”, as opposed to a “token” or knowledge, such as a password (Jain et al., 2002). Jain et al. (2002) state that a biometric modality should strive for the following characteristics: universality, uniqueness, permanence and collectability. Universality describes the possibility of all individuals sharing the biometric in general, but does not include the similarity of the biometric characteristics. For example, most of the population will have two eyes, each of which will include irises, pupils, and sclera. Each iris pattern will be distinct to the individual, but each individual will have patterns. Uniqueness describes the possibility that no two individuals shared the same biometric characteristics , while permanence describes the ability of the biometric to remain stable over time. The variance in irises is insignificant over the lifetime of an individual, making it a good candidate for a reliable biometric (Jain et al., 2002; National Research Council, 2011), although recently published evidence states that the iris may not be as stable over time as once thought (Baker, Bowyer, Flynn, & Phillips, 2006; Gilroy, 2012). Collectability refers to the level of ease with which a high-quality biometric sample is collected (Jain et al., 2002; National Research Council, 2011).

2.2 Iris Recognition

Iris recognition is defined as a process to automatically identify an individual based off random, unique patterns within his or her iris, and has been rising in popularity to become a common form of biometric identification (Daugman, 2009).

The iris is “the muscle within the eye that regulates the size of the pupil, controlling the amount of light that enters the eye” (National Science and Technology

Council, 2006, p. 1). In non-technical language, the iris is the colored ring that surrounds a pupil and separates the pupil from the sclera. An iris's color and structure are hereditary, but the random patterns in the iris are not (Daugman, 2009). The tissue that makes up these random patterns begins to develop soon after conception and is, for the most part, complete by the eighth month of gestation and said to be stable over time (Daugman, 2009). A sample iris image can be observed in Figure 2.1.

Automated iris recognition is a relatively new concept. John Daugman's iris recognition algorithm was patented as recently as 1994 (National Science and Technology Council, 2006). However, the concept of identifying an individual was developed much earlier, with the initial concept of iris recognition proposed by Dr. Frank Burch in 1936 (National Science and Technology Council, 2006). However, ophthalmologists Dr. Leonard Flom and Dr. Aran Safir made the first claim stating that no two irises are alike in 1985. Dr. Flom and Dr. Safir received a patent, prior to the patent awarded to John Daugman, for the concept of iris identification in 1987 (National Science and Technology Council, 2006).

While the notion of unique irises originates from Flom and Safir, Dr. John Daugman (Daugman, 2003; Daugman, 2009) developed the algorithm used to identify the iris. Daugman's algorithm can automatically localize the iris and identify it, and the first prototype of an iris recognition device that uses this algorithm was built in 1995 (National Science and Technology Council, 2006).

The iris is typically captured using a high-resolution, high-quality camera that illuminates the eye with near infrared light. Near-infrared wavelengths illuminate the iris patterns more efficiently than visible light wavelengths and are also preferred for their ability to illuminate irises with darker pigments (Daugman, 2009).

An iris must be located prior to its processing. This task is accomplished by locating the face and referencing characteristics on the face. These characteristics, or "landmarks", typically consist of the nose or mouth (National Science and Technology Council, 2006). Once the iris is located, the system must then locate the inner and outer bounds that separate the iris from the pupil and sclera (Daugman, 2003; Daugman, 2009). An iris localized from the pupil and sclera is shown in Figure 2.1.

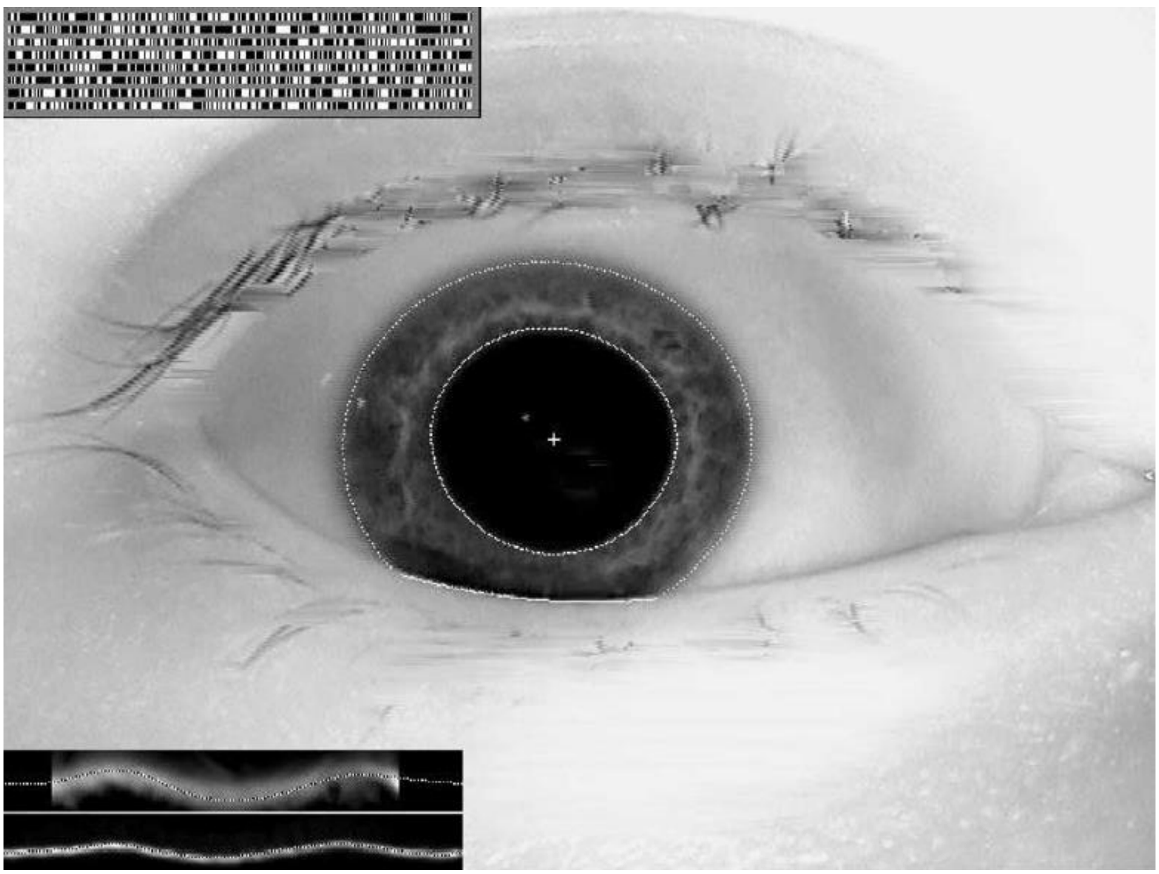


Figure 2.1. Image depicting the localization of the iris from the pupil and sclera. Adapted from "New methods in iris recognition" by J. Daugman, 2007, *IEEE Transactions on Systems, Man, and Cybernetics-Part B: Cybernetics, 37*(5), p. 1168. Copyright 2007 by IEEE.

2.3 Principles of Performance

Many biometric systems require the user to be enrolled prior to verification. The enrollment process requires a presentation, and in some case multiple presentations, of the user's iris to a sensor to capture the unique features found within that iris (Dunstone & Yager, 2009). Once the enrollment process is completed, the features are converted into a template and stored in a database. Errors may occur during enrollment, and these are defined as a failure to enroll (FTE) (Dunstone et al., 2009).

Once the user has been enrolled, he or she becomes a valid, genuine user of the system. However, errors can still occur after enrollment. In certain cases, when interacting with the device, a user may present his or her biometric incorrectly, which can result in a failure to acquire.

There typically exist two types of users within a biometric system: genuine and impostor. A genuine user is a user who has already enrolled in the biometric system and possesses a valid template within the designated template database (National Research Council, 2011). In a perfect situation, the user makes a genuine claim and is granted access by the biometric system. An imposter is a user attempting to gain access through the biometric system without having a valid template or being previously enrolled (National Research Council, 2011). Occasionally, a genuine user will be denied access, which is considered a false reject. False rejects may be caused by poor-quality images (Grother & Tabassi, 2007), possibly due to human error or an error with the biometric system (Kukula et.al, 2007). Further, poor image quality (Grother et al., 2007) may allow an impostor user to be falsely granted access into the system, which is considered a false accept.

2.4 Introduction to Habituation

Habituation is defined in the social sciences as "a behavioral response decrement that results from repeated stimulation and that does not involve sensory adaptation/sensory fatigue or motor fatigue" (Rankin et al., 2009, p. 136). Kukula et al. (2007), in the context of hand geometry, state that habituation occurs when a user is subconsciously capable of producing consistent hand geometry scores. Thompson and Spencer (1966, p. 17) define habituation as "a response decrement as a result of repeated stimulation" but also "results from very rapid stimulation". These two definitions are similar.

The idea of habituation is not new. Quotes have been extracted from the writings of Plato and Fables that reference this concept (Thompson, 2009). In-depth research that observes habituation in animals and humans has been ongoing since the beginning of the 20th century (Thompson, 2009). New terms began appearing in journals and documents during the early stages of this research, such as "acclimatization" (Thompson, 2009, p. 127), "accommodation" (Thompson, 2009, p. 127), and " negative adaptation" (Thompson, 2009, p. 127), all of which have been used to describe the effects of habituation (Thompson, 2009). Kukula et al. (2007), who define a model of habituation using hand geometry, with acclimation, partial habituation, present similar terms in a paper and full habituation identified as steps in the "habituation" process. Acclimation occurs when "the user adapts his techniques to achieve proper match of the biometric template" (p. 242). Partial habituation is described as the point when no new techniques are used to achieve matches, and full habituation is the point when the user begins to use subconscious techniques to obtain a successful result (Kukula et al., 2007).

Many researchers claim that habituation is the most basic form of learning (Rankin et al., 2009; Thompson, 1966; Thompson, 2009; Yehuda, Shtrom, Peter, 1979). Thompson (2009, p. 2) states that habituation is “an instance of elementary learning”. In a study conducted by Yehuda et al. (1979), the achievable habituation level is theorized to be affected by the individual’s general intelligence. Two types of intelligence are proposed by Yehuda et al. (1979): crystallized and fluid intelligence. Crystallized intelligence incorporates social patterns and learning, while fluid intelligence deals more with the adaptation of an environment. Yehuda et al. (1979) state that fluid is based not on experiences but rather on the development of the subject’s brain. To appropriately measure this intelligence, the researchers created three groups to represent three different intelligence levels: “gifted”, with an IQ of 140 or above, “normal”, with an IQ between 95 and105, and “mentally slow”, with an IQ in the range of 45-55. Each of the groups was exposed to a flickering light (stimulus) at a pattern of ten seconds on and twenty seconds off. This pattern was repeated until the response level (response), which was measured according to neural process level, was one-third of the maximum response level observed by that subject (Yehuda et al., 1979). A count of the stimulus pattern was also recorded to observe any decreases in the required stimulus repetitions (Yehuda et al., 1979). The experiment yielded results suggesting that normal and gifted groups systematically reduce response levels. The group with the lowest IQ scores showed decreases in its response levels, but no distinguishable patterns were observed to indicate that habituation progressed in the low-IQ group. The improvements observed in the normal and gifted groups that were not observed in the low-IQ group suggested a relationship between intelligence level and habituation patterns (Yehuda et al., 1979).

These results also coincide with the "behavioral response decrement" mentioned in the definition of habituation proposed by Rankin et al. (2009).

Thompson and Spencer (1966) refer to habituation as "relatively permanent", a result of spontaneous recovery. From this research, the authors develop nine attributes of habituation based on the findings from stimulus experiments performed on typical house cats (Thompson et al., 1966). These nine attributes are reviewed by Rankin et al. (2009) and further developed, resulting in the development of a tenth attribute. Of these attributes, four are directly related to the methodology proposed in this thesis. Those four attributes, quoted below, are taken directly from Rankin et al. (2009).

The first attribute is defined as the "repeated application of a stimulus results in a progressive decrease in some parameter of a response to an asymptotic level" (Rankin et al., 2009, p. 135). This characteristic states that the more an individual performs a stimulus, the more the response will decrease in some way. In terms of iris recognition, the user's interactions with the iris device become more consistent, which can result in the user requiring less time and fewer presentations to donate the desired iris sample.

The second attribute, which is the third characteristic listed in Rankin et al. (2009), is "after multiple series of stimulus repetitions and spontaneous recoveries, the response decrement becomes successively more rapid and/or more pronounced" (Rankin et al., 2009, p. 136). This characteristic was tested in this thesis through the separation of visits. Not only did the subject interact with the iris device multiple times during a visit, but the subject also returned for multiple visits, which created stimulus repetition.

The third attribute, listed as the fourth characteristic in Rankin et al. (2009), says that "other things being equal, more frequent stimulation results in more rapid and/or more pronounced response decrement, and more rapid spontaneous recovery" (Rankin et al., 2009, p. 136). The more frequently a stimulus occurs, the more rapidly an individual becomes habituated. With iris recognition, the more a user interacts with the device, the faster that user will become habituated, which may result in an increase in performance, sample quality or other metrics.

The fourth characteristic, which is the tenth characteristic listed in Rankin et al. (2009), states that "some stimulus repetition protocols may result in properties of the response decrement" (Rankin et al., 2009, p. 138). This characteristic describes the possibility that habituation can take less time if the stimulus is properly and repeatedly shown over a period of time. The stimulus, in the case of iris recognition, is either the camera itself prompting the subject to enter the capture area or a test administrator or operator performing the same task. This attribute alludes to proper training and feedback, which is a focus in Theofanos et al. (2007) and is important in iris recognition. If the user is properly trained to use the device through robust training sessions and is provided with the correct feedback, than habituation may occur more rapidly and produce an increase in performance.

A common theme in the reviewed literature is the concept that habituation is a function of repeated use (Haines, 2005; Kukula et al., 2007; Rankin et al., 2009; Theofanos et al., 2007; Thompson, 2009; Thompson et al., 1966; Yehuda et al., 1979). In a biometric context, these concepts translate to frequency of visits and the number of presentations per visit. It may be that habituation rates will occur more quickly the more a user visits and interacts with a biometric device (Kukula et al., 2007; Theofanos et al., 2007).

2.5 Examination of the Terms Surrounding Habituation

A significant issue noticed during the literature review was the many and varied definitions of habituation used by the biometric community. Furthermore, terms are used as synonyms in the literature and lead to claims of inconsistencies. Kukula et al. (2007) and Thompson (2009) use "acclimatization" or "acclimation" when defining habituation. Other terms used in the literature are listed in Table 2.1. Terms listed multiple times reflect the multiple definitions discovered.

Table 2.1. *Definitions of common terms associated with habituation*

Term	Author	Author Definition	Dictionary Definition (Merriam-Webster's online dictionary, 2013)
acclimation	(Kukula et al., 2007, p. 242)	user adapts his or her techniques to achieve a proper match with the biometric template	the process or result of acclimating; especially physiological adjustment by an organism to environmental change

adaptation	(Thompson, 2009, p. 127)	(only mentioned in passing)	the act or process of adapting; adjustment to environmental conditions
dishabituation	(Thompson, 2009, p. 127)	"the restoration of a habituated response by extraneous stimulation."	(not defined in dictionary)
full habituation	(Kukula et al., 2007, p. 242)	"user matches biometric template by subconscious techniques"	(not defined in dictionary)
habituation	(Rankin et al., 2009, p. 136)	"the behavioral response decrement that results from repeated stimulation and that does not involve sensory adaptation/sensory fatigue or motor fatigue"	"the process of habituation or the state of being habituated; decrease in responsiveness upon repeated exposure to a stimulus"

habituation	(M1.5, 2003)	“familiarity with the workings of a biometric system and/or application”	“the process of habituation or the state of being habituated; decrease in responsiveness upon repeated exposure to a stimulus”
habituation	(Kukula et al., 2007, p. 242)	“the continued use of a biometric device”	“the process of habituation or the state of being habituated; decrease in responsiveness upon repeated exposure to a stimulus”

habituation	(Rankin et al., 2009; Thompson, 1966; Thompson, 2009, & Yehuda et al., 1979)	"instance of elementary learning"	"the process of habituation or the state of being habituated; decrease in responsiveness upon repeated exposure to a stimulus"
partial habituation	(Kukula et al., 2007, p. 242)	"no new adaptation of technique to achieve proper match of biometric template"	(Not defined in dictionary)

Common words noticed in the above definitions included "adapt", "repeats", "repeated use", "familiarity", "technique", and "decreases in response". It was theorized that all of these terms attempted to describe the same habituation effect. To validate this theory, the discovered common terms were loaded into a thesaurus tool, Visual Thesaurus, to examine the overlaps between habituation and the discovered terms. This tool displays the common synonyms of an entered term in a web-like fashion. The terms were loaded into the tool to find a connection between the discovered terms and the term "habituation". Figure 2.2 shows the beginning of this synonym analysis, which was commenced by loading the term "habituation".

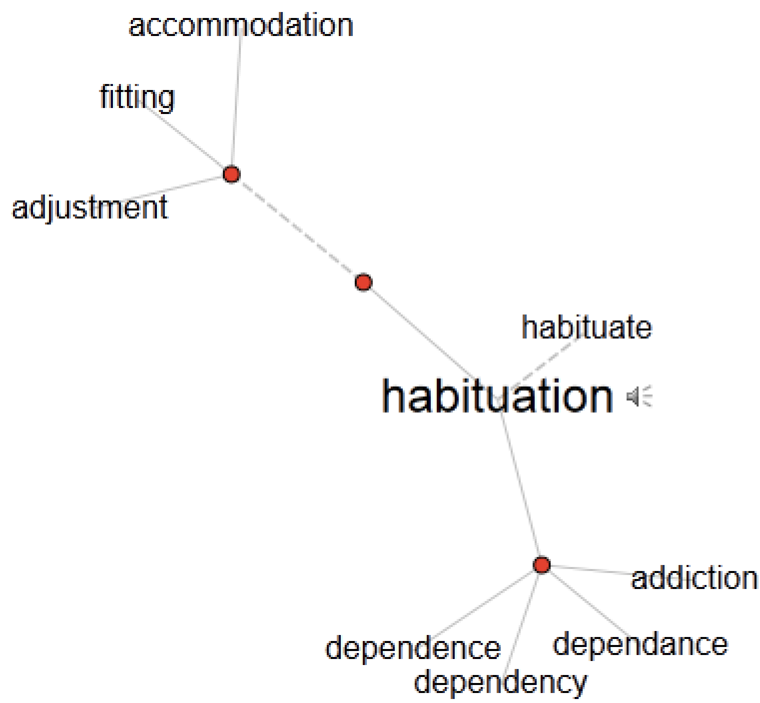


Figure 2.2. Display of synonyms for “habituation” in Visual Thesaurus (Visual Thesaurus, 2013)

Two synonyms for which examination was deemed important were “accommodation” and “adjustment” because they were identified in Table 2.1 and found in the biometric literature (Thompson et al., 1966, pp. 17; Thompson, 2010, pp. 127). The term “adjustment” was loaded into Visual Thesaurus, but no results were found. The term “accommodation” was also examined using the Visual Thesaurus tool, and Figure 2.3 shows the resulting synonyms.

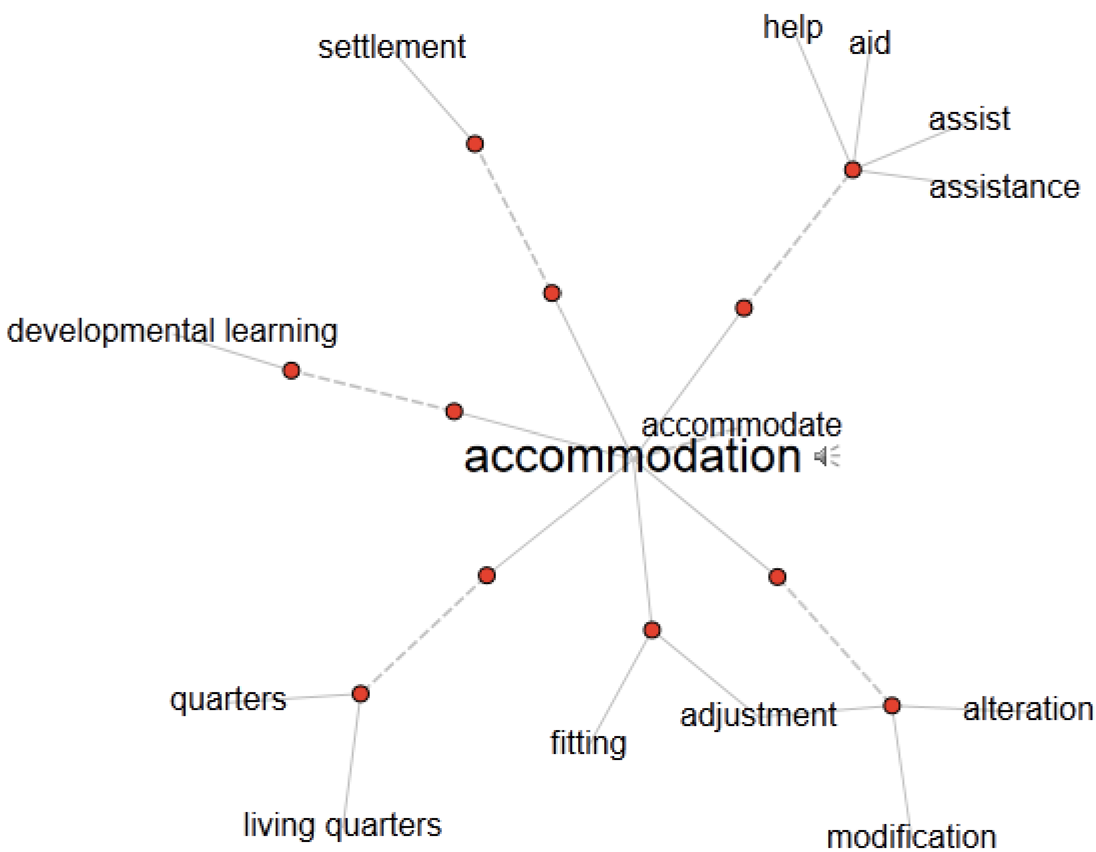


Figure 2.3. Display of synonyms for "accommodation" in Visual Thesaurus (Visual Thesaurus, 2013)

One synonym identified during the process was "developmental learning". A similar term is used in Rankin et al. (2009), Thompson (1966), Thompson (2009) and Yehuda et al. (1979), in which the authors refer to "elementary learning". This result showed some connection between the terms and "habituation".

One final examination of synonyms focused on the frequent appearance of "repeats" or "repeated stimulus" in the literature. A number of terms surrounding "frequent use" were loaded into Visual Thesaurus and each synonym was further examined. This analysis resulted in the identification of the term “use”. Figure 2.4 shows the collection of synonyms for this word.

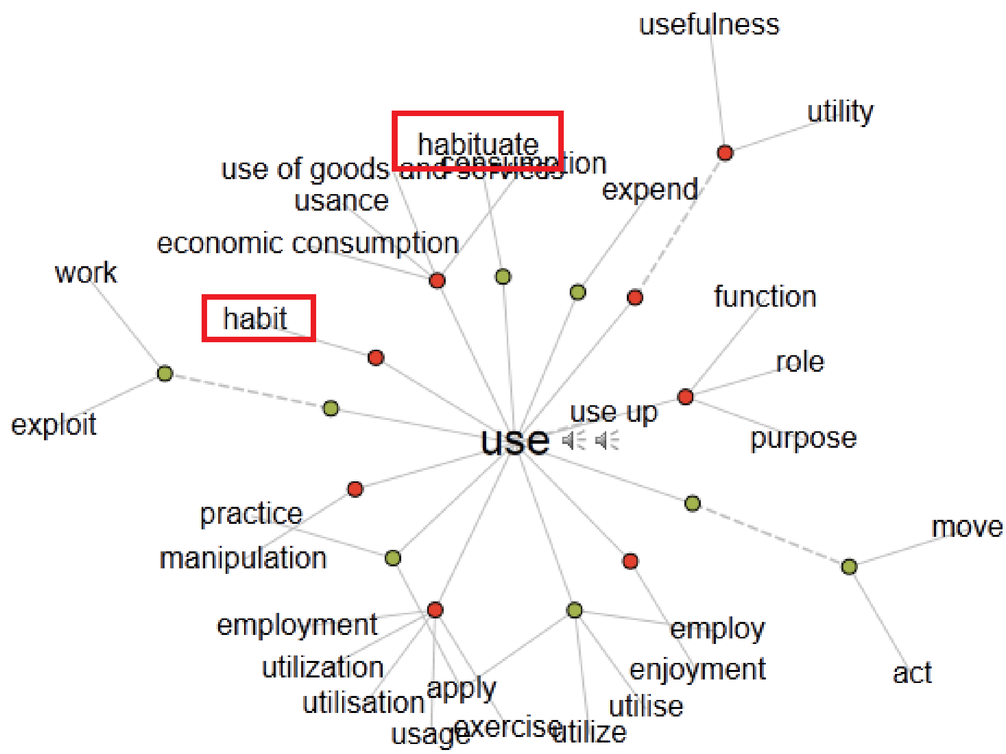


Figure 2.4. Display of synonyms for “use” in Visual Thesaurus (Visual Thesaurus, 2013)

Two of the synonyms for “use” in Figure 2.4 directly led to “habituation”. “Habituate” and “habit” both branched off the word “use”. These results made a connection between “frequency of use”, or “repeats”, and the definition of habituation.

This examination of the synonyms surrounding “habituation” was the first phase in determining that the concept of habituation was not consistent in the biometric community. Using the terms referencing habituation found in the literature, Visual Thesaurus showed a connection between those terms and the term “habituation”. Each term was loaded into Visual Thesaurus along with any viable synonym that appeared in the “web of synonyms”. A connection was identified between the discovered terms in the literature and “habituation”, but no term loaded into Visual Thesaurus was a true synonym of “habituation”, other than “use” because “habituation” did not show up directly in any of the performed synonym searches. This result suggested that the terms used to describe habituation were not only inconsistent, but they also did not truly describe habituation. This analysis was used in the design of the habituation survey discussed later.

2.6 Industry Drivers

Biometric systems are said to show a number of benefits over non-biometric security systems. The National Research Council (2010) stated that automatically recognizing individuals through biometrics can “reduce error rates, improve accuracy, reduce fraud, present opportunities for circumvention, reduce costs, improve scalability, increase physical safety, and improve convenience” (p. 20). All of these benefits may be observed in a well-defined environment, but each implementation is situational. While a certain situation may be capable of improving scalability and accuracy, it may be unable to reduce costs. A primary focus of this particular habituation research was to identify time-on-task and number of visits as a prime indicator of the presence of habituation. Assuming an individual can become habituated to an iris recognition camera, being habituated should reduce the amount of interactions required, lead to less time required per subject and increase the system’s throughput.

Frost and Sullivan (2011) state that iris recognition technologies have received interest for a wide variety of applications. However, there is a need to improve the efficiency of the deployed devices. Such iris devices have been used as methods of authentication and identification in homeland security and law enforcement (Frost et al., 2011), both of which require high security and efficiency. Time-on-task and throughput are important factors in the performance of a biometric system.

Time (with respect to an access control biometric system) was defined as, “the length of time taken to complete an activity” (Elliott, Kukula, & Lazarick, 2009, p. 1). Multiple types of times exist within this definition, including total transaction time, biometric transaction time, subject interaction time, biometric subsystem processing time, biometric subsystem decision time, and external control access time (Elliott et al., 2009).

The total transaction time encompasses all of the biometric subsystem times that are mentioned above. This time begins with the user making a claim of identity and ends with some sort of external access control, such as a gate opening, that allows access to the system user (Elliott et al., 2009). The biometric transaction time is the time allotted to the processing of the biometric sample. This time begins with the presentation of the biometric and ends with the biometric system making a matching decision. These two times incorporate multiple subsystem times. The subject interaction time is the time given for the subject to claim identity and present the biometric (Elliott et al., 2009). The biometric subsystem processing time represents the entire acquisition of the biometric and its processing. This includes any segmentation, localization, or template creation. The decision subsystem time represents the time taken for the system to make a decision based on the biometric sample/template, usually to accept or reject it. The external access control time is ascribed to any time needed for tasks undertaken after a decision, which usually includes opening a gate or door (Elliott et al., 2009). This study focused prominently on the subject interaction time mentioned in Elliott et al. (2009) and referenced only the time during which the user presents a biometric to the device.

2.7 The HBSI Model

Because habituation attributes changes in a biometric system's performance to the user, an examination of the interaction between the human and the system was required for this study. The Human Biometric Sensor Interaction (HBSI) model focuses on the interaction that occurs between a human and a biometric sensor and was initially developed while observing abnormal subject-to-sensor interactions during data collections at Purdue University. Although initially created based on the results of fingerprint data collection, the human biometric sensor interaction model is designed to encompass all biometric modalities. A framework for the errors of the HBSI model can be observed in Figure 2.5.

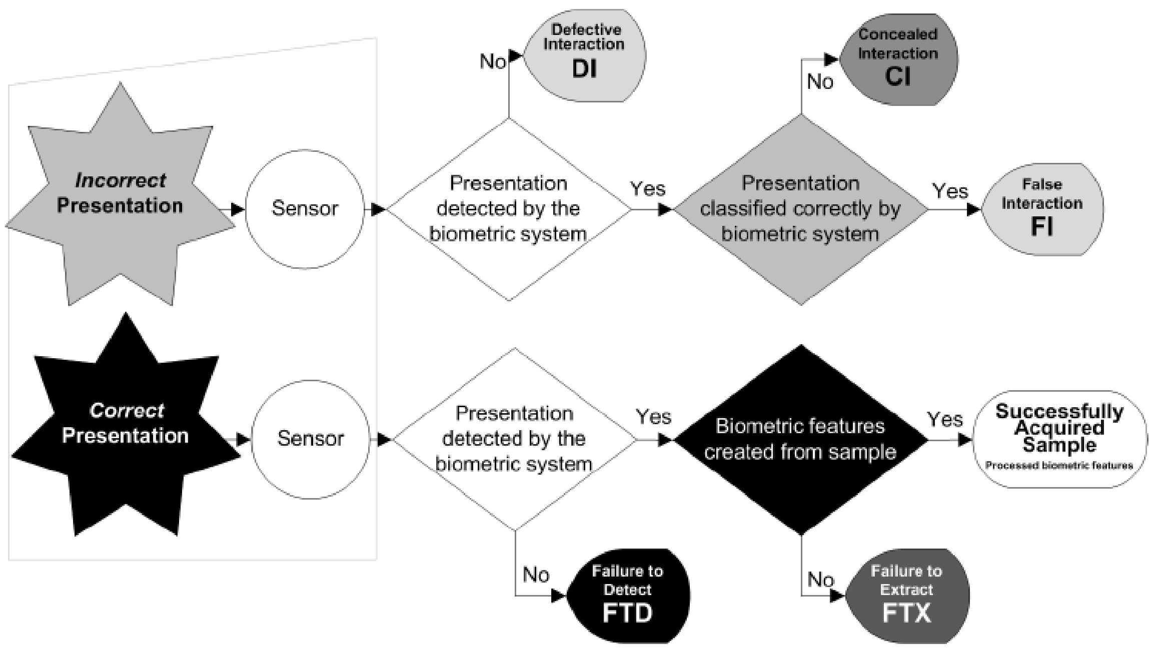


Figure 2.5. Framework for the HBSI Model. Adapted from "A Definitional Framework for the Human-Biometric Sensor Interaction Model" by S.J. Elliott and E.P. Kukula, 2009. Copyright 2009 by BSPA and Purdue University

The main purpose of the model is to determine how a user, system and biometric sensor interact with each other to determine the biometric system's functionality (Elliott & Kukula, 2009). Elliott and Kukula (2009, p. 1) claims the main research questions that were addressed with the HBSI model are:

- How do users interact with biometric devices?
- What errors do users make?
- What are the most common errors or issues that users face?
- Why do users continually make these interaction errors and how do we prevent or avoid them from happening?
- What level of training and experience is necessary to successfully use biometric devices?

The model is divided into two sections, incorrect and correct presentation, that are determined by the actions of the device user. The incorrect section of the model involves any errors that occur when the biometric presenter makes an erroneous or incorrect presentation to the biometric device. The correct presentation section of this model includes any errors that occur when a user correctly presents to the device. Incorrect presentations have the following errors: defective interaction, concealed interaction, and false interaction. Correct presentations have the following errors: failure to detect, failure to extract, and successfully acquired samples (Elliott, & Kukula, 2009).

Determining where an error occurs in this model helps to understand why the error has occurred, especially if the type of presentation is also understood. For instance, if a defective interaction occurs, it is known that the user presented correctly, but the system was unable to detect the presentation. However, if a failure-to-extract occurs, it is known that the presentation was detected, but due to issues with the incorrect presentation such as bad image quality, the sample was unable to be processed (Elliott, Senjaya, Kukula, Werner, & Wade, 2010). This problem could be solved by creating better training protocols. Furthermore, as a user becomes more habituated, the knowledge of using the device, in theory, increases and possibly causes a decrease in incorrect presentations to occur. This situation aligns well with the habituation definitions and concepts in the literature. However, the types of errors that occurred during the data collection performed for this study were not recorded or used in the results section of this thesis.

2.8 Previous Work

Previous research has been conducted to directly measure the effect of habituation on a biometric system (Kukula et al., 2007; Theofanos et al., 2006). In a study completed by Kukula et al. (2007), the effect of habituation is examined in a hand geometry system. The scoring with this specified hand geometry system is between 0-100, with zero being the best possible score and 100 the worst possible score. The study consists of seven weeks, and when the time comes for a subject to use the device, it requires three consecutive scores under 30. To observe the impact of habituation, the subjects are divided into four groups. Group 1 is enrolled in the system in the first week and is required to use the system each subsequent week until the final week. Group 2 is enrolled during the first week but does not use the system again until week seven. Group 3 does not use the system until week seven and is used as a control group that represents non-habituated users. Group 4 is enrolled during week two and is meant to represent a typical access group that uses the system only once a week. In weeks two, four, and six, the subjects in Group 4 do not require three consecutive scores under 30 (Kukula, et al., 2007). This study focuses on both the stability of the scores and the number of attempts required to fulfill the three-consecutive-score requirement. As hypothesized by Kukula et al. (2007), Groups 1 and 4 show an improvement in hand geometry scores as the subjects progress through the seven visits but also show an improvement in the number of attempts required over the course of the entire experiment. This result can be observed in Figure 2.6, which plots the number of attempts required by subjects for certain visits.

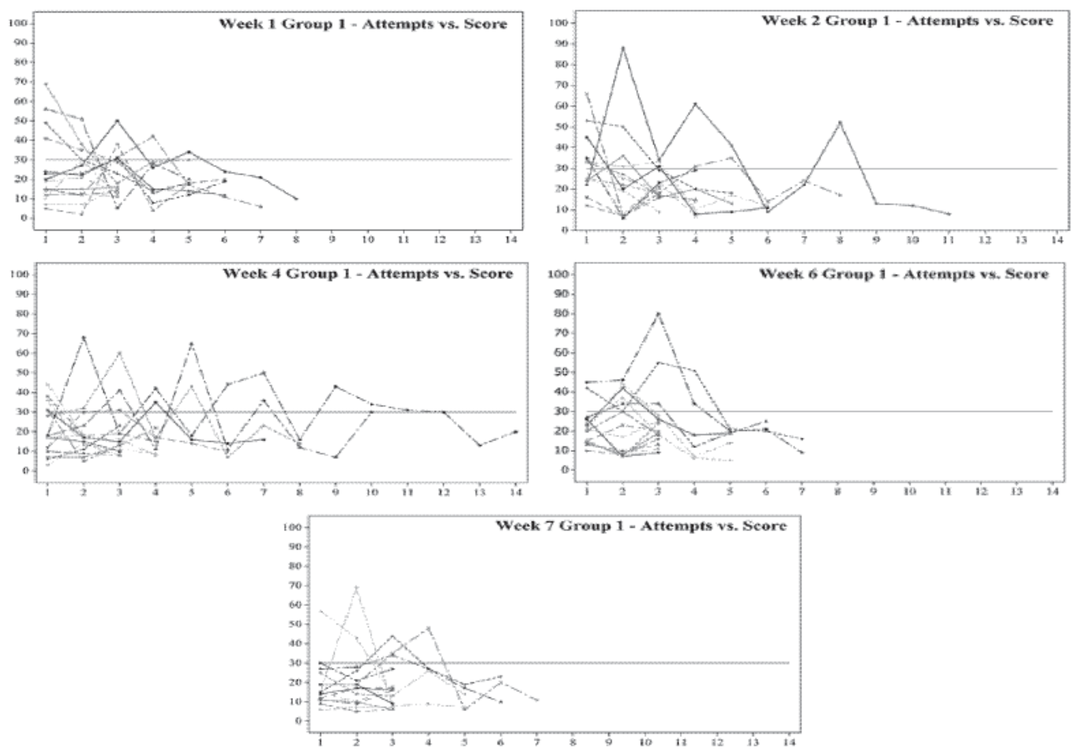


Figure 2.6. Graphical representation of the number of attempts over time. Adapted from "Defining habituation using hand geometry" by E. Kukula, S. Elliott, B. Gresock, N. Dunning, 2007, *IEEE Workshop on Automatic Identification Advanced Technologies, p.* 244. Copyright 2007 by IEEE.

The number of attempts in the above plots appear to decrease, and a noticeable improvement can be observed by Week 7. The results of this study suggest Groups 1 and 4 are moving towards full habituation. Groups 2 and 3 show no significant difference in number of attempts and hand geometry scores, suggesting no habituation has occurred (Kukula et al., 2007).

In Theofanos et al. (2006), a large group of subjects is asked to interact with a fingerprint recognition system during a lunch period. This study consists of two trials, with one trial focusing on habituation with feedback and the other on habituation without feedback. Twenty-nine individuals participate in the first trial, while 28 participate in the second trial. Frequency and number of attempts are not recorded in the study, but the subjects are encouraged to use the fingerprint system as much as possible to reflect the effects of habituation. Like Kukula et al. (2007) and Rankin et al. (2009), this study suggests a relationship between habituation and the frequency of a given stimulus, in this case, the subject being asked to present his or her fingerprint to a sensor (Theofanos et al., 2006). The results of this experiment show no significant effects of habituation on sample quality without feedback, but significantly higher quality scores are observed when feedback is given (Theofanos et al., 2006).

2.8.1 Instruction and Feedback

Theofanos, Stanton, Michaels, and Orandi (2007) examine the relationship between the performance of an individual and an instruction type. In this study, during initial subject training, different types of instructions are given in the form of posters, verbal instructions, and videos. Subjects are asked to interact with a fingerprint device that captures four fingers simultaneously based off the instruction type given. The results of this study suggest that posters are ineffective at properly training subjects to use the device, as this group has the most trouble completing the task, with only 56% of subjects being able to complete it. Groups that receive video and verbal instructions perform equally better than the group that receives poster instructions, with the subjects preferring verbal instructions. With an operator's assistance, the completion rate of the task increases to 98%. (Theofanos et al., 2007). The results on feedback also suggest that performance can be affected by the instructions given to the subject. Yehuda et al. (1979)

note that habituation may be affected by intelligence level; therefore, will dynamic instruction types improve habituation rates?

2.8.2 Perception and Comfort

The perception of a biometric system is an important aspect of its acceptability (Heckle, Patrick, & Ozok, 2007). Much of a biometric system's acceptance also relies on the context in which it is implemented. This context, in turn, affects the level of comfort a user feels with the system and causes a change in the learning process associated with the device (Heckle et al., 2007). One study asks participants to rank their level of comfort when using a biometric system for purchasing a book from an online bookstore (Heckle et al., 2007). Subjects are asked to use a fingerprint device when gaining access to the bookstore and are then asked to purchase a book using either a personal or corporate credit card. Eighty-eight percent of the subjects consider using a fingerprint device "beneficial" when purchasing with a personal credit card. Only 33% of subjects opt to use the current username/password configuration. Forty-six percent prefer to use a username/password technique with personal information, while 58% prefer it with corporate information (Heckle et al., 2007).

In a dynamic signature verification study, the context of signing is found to be important to the development of a test protocol. The way an individual signs depends on the context in which the signature is required, such as signing a grocery receipt or signing a will at a lawyer's office (Elliott, 2004, p. 643). This result is similar to that identified in Heckle et al., (2007), as the context of the system may influence the presentation of a biometric sample.

Pritikin (2012) theorizes that future user perception of iris recognition will be positive due to its being a non-contact system that is less invasive and capable of decreasing wait times. With this improved comfort, iris recognition would also decrease overhead that arises due to concerns raised by device users (Pritikin, 2012). In theory, this perception would increase the chance of habituation in a user of an iris recognition system.

2.8.3 Frequent Use

It has been stated that habituation should occur naturally in a biometric system that is used at a high frequency (Elliott, 2004; Tamer & Elliott, 2009).

Highly habituated users have been observed in the context of time and attendance (Tamer et al., 2009). An individual is typically clocking in or clocking out in this situation. Therefore, the user is interacting with the device multiple times a day, causing an increase in the rate of habituation. Due to the high frequency of use, biometrics in a time and attendance application typically result in a highly habituated work force (Tamer et al., 2009). No results exist that identify the existence of habituation in this situation, but this paper concluded that using a device at a high frequency results in higher habituation rates.

CHAPTER 3. METHODOLOGY

The goal of this thesis was to determine that no consensus of habituation among biometric experts exists and that the existence of habituation can be shown using time-on-task as a metric. To achieve the first goal, a survey was constructed for the biometric community to qualitatively gauge the way experts defined habituation.

To confirm the prior existence of habituation (Theofanos et al., 2006; Kukula et al., 2007), iris data collection exercises were quantitatively analyzed in terms of the time needed to capture simultaneous irises as a function of the time-on-task metric, which is further defined in this chapter. The data collection exercises utilized, which occurred in 2010 and 2012, provided sufficient, but not ideal, conditions to show the existence of habituation. Both exercises provided multiple visits and multiple captures per visit that would allow for habituation to occur. However, bias may have been introduced because the subject recruitment was not completely random. The results of the quantitative analysis performed on these iris data collections were placed in the context of the qualitative survey results to create a comparison between the two.

The initial hypothesis for the qualitative portion of the study stated that biometric experts do not universally agree on the definition of habituation, but do agree that time-on-task is a reliable metric of habituation. The initial hypothesis for the quantitative analysis stated that time-on-task is an efficient metric with which to show the existence of habituation in an iris recognition system.

3.1 Habituation Survey Exercise

The habituation survey methodology served three purposes. First, this survey was used to investigate the disparities in how experts define habituation. Second, the survey built confidence that the methodology used for the data collection efforts in this thesis would provide the best conditions under which to measure habituation. Third, the habituation survey attempted to determine whether biometric experts believe time-on-task correlates to habituation in an iris system.

The survey consisted of 12 questions. Ten of these questions included both closed and open-ended responses. The remaining two questions asked respondents only for their demographic age and biometric experience. The closed portion of each question was designed to provide an overall idea of the biometric experts' background prior to analyzing the open-ended portion. The open-ended part of each question was used to make conclusions on the consistency of habituation definitions, the validity of the proposed data collections and the ability of the time-on-task metric to indicate habituation. The selection of questions was based on the literature review included in this thesis. The questions asked in the survey are listed in Appendix F.

3.1.1 Analysis Methods for the Habituation Survey

The responses to the open-ended portions of the questions were analyzed by identifying common themes. A perspective or concept was considered a "common theme" when that concept was present in more than one participant's response to a given question, meaning the concept was shared among multiple biometric experts. Each common theme was reported along with the number of times that theme appeared in the analysis of an individual question. These themes were used to make conclusions on the disparities in the existing definitions of habituation. To be considered universally understood, each theme had to appear in nearly every expert's response. Because a common theme is a concept shared by multiple biometric experts, it was considered a crucial component of habituation, regardless of whether it was considered universally understood or misunderstood.

3.1.2 Sampling for the Habituation Survey

The participants for the habituation survey consisted of biometric experts affiliated with the BSPA Labs. A list of email addresses of biometric colleagues was created and a standard email was sent to invite their participation. Out of the 30 emails sent for this habituation survey, 13 individuals participated in the survey.

3.2 Data Collection Exercises

A data collection exercise that took place between 2012 and 2013 was utilized to characterize habituation trends in an iris recognition system with the time-on-task metric. This exercise was part of a funded study that attempted to observe aging in an individual's biometric characteristics. Because the overarching study was a longitudinal data collection effort consisting of eight visits, with an iris recognition system included as part of the study, this data collection method was suitable for the requirements of this thesis.

The data collection exercise consisted of eight visits. On the first visit, the subject completed a consent form, copied in Appendix B, that allowed for the analysis of the individual's biometric data. The data used by this thesis, which included camera process logs and iris images, were captured using an Aoptix Insight Duo iris camera manufactured by Aoptix Technologies.

At each visit, the subject presented his or her irises to the iris camera and attempted to submit at least 20 successful captures, with a maximum of 25 opportunities. This thesis considered a capture that resulted in both irises being captured during a given attempt to be a successful capture. As each capture attempted to collect both irises simultaneously, approximately 40-50 iris images were stored for each subject during the 2012 data collection exercise.

Due to the accidental deletion of images by a test administrator during Visit 8, two subjects were asked to return for re-collection, resulting in a final Visit 9 because these images were required for the overarching biometric aging study. Because these images could have affected the habituation results, only these two subjects returned for a ninth visit. The images for Visit 9 were misplaced during their importation into the ICBR (Purdue University) database, resulting in only the timing data being available for this visit. Thus, the examination of time-on-task was the only variable that included Visit 9 data in the forthcoming quantitative analysis.

3.2.1 Units of Measurement in the Data Collection Exercises

In this thesis, time-on-task was considered to be the change in between when the capture process began and when it ended, in milliseconds. This variable was quantified by differentiating changes in the iris camera process states and the associated timestamp with the changes. These state changes were parsed from process logs pulled from the iris recognition camera and were exported after each subject. The state changes were also synonymous to changes in processes performed by the device and were accompanied by an LCD monitor display on the device that provided feedback to the subject. Figure 3.1 shows three examples of LCD screens displayed by the Aoptix Insight Duo that provided feedback to the subject. These three screens were also the screens that prompted the capture's start and end points to the subject.

Figure 3.1. Sample feedback screens displayed by the Aoptix Insight Duo (Aoptix Technologies, 2012)

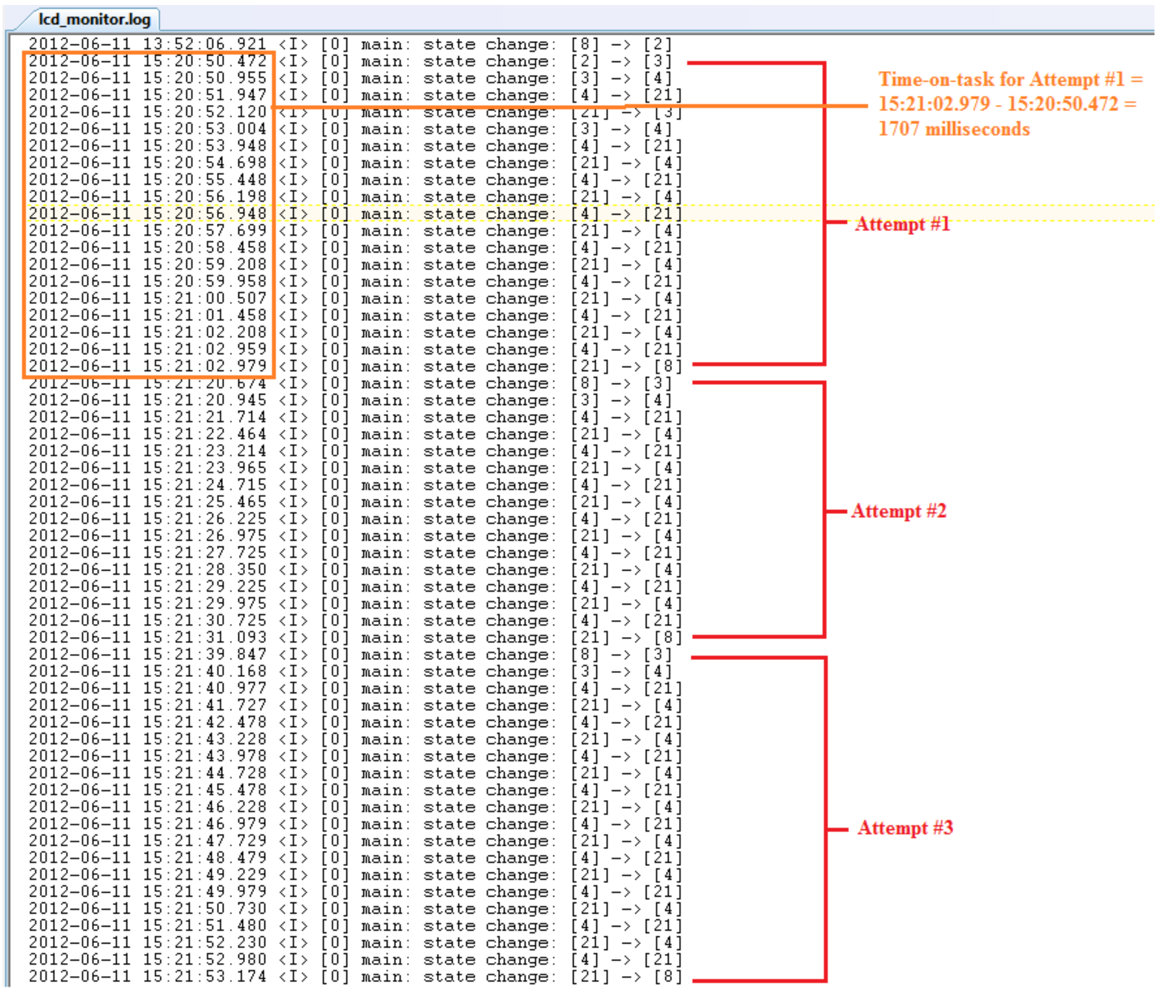
Each process state was associated with a state ID inside the camera. This state ID was used to determine state changes in the process logs. See Table 3.1 to see the state identification codes with a description of each state's meaning.

Table 3.1. *State IDs given for the Aoptix process logs*

State ID	Description
1	Initializing
2	Standby
3	Enter (Ready)
4	Look Here
5	Wait
6	Retry
7	Enroll Capture Complete
8	Capture Complete
9	ID Complete – Match found
10	ID Complete – Match not found
11	System Error
12	Call Operator
13	Failed to Acquire
14	See Operator
15	Shutting Down
16	EnrollAckSaved
17	EnrollAckReject
18	PacsShowCard
19	PacsIrisRecognition
20	PacsIDPass

21	Look Here (Alt)
22	Error
23	Please Open Eyes Wide
24	Invalid Card
25	Remove Eyeglasses

The state changes were logged as [initial state] -> [resulting state] in the process logs. See Figure 3.2 for an example of the process logs extracted from the camera after each subject's visit and how they provided a means for the time-on-task calculation.



```
lcd_monitor.log
2012-06-11 13:52:06.921 <I> [0] main: state change: [8] -> [2]
2012-06-11 15:20:50.472 <I> [0] main: state change: [2] -> [3]
2012-06-11 15:20:50.955 <I> [0] main: state change: [3] -> [4]
2012-06-11 15:20:51.947 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:20:52.120 <I> [0] main: state change: [21] -> [3]
2012-06-11 15:20:53.004 <I> [0] main: state change: [3] -> [4]
2012-06-11 15:20:53.948 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:20:54.698 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:20:55.448 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:20:56.198 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:20:56.948 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:20:57.699 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:20:58.458 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:20:59.208 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:20:59.958 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:00.507 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:01.458 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:02.208 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:02.959 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:02.979 <I> [0] main: state change: [21] -> [8]
2012-06-11 15:21:20.674 <I> [0] main: state change: [8] -> [3]
2012-06-11 15:21:20.945 <I> [0] main: state change: [3] -> [4]
2012-06-11 15:21:21.714 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:22.464 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:23.214 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:23.965 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:24.715 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:25.465 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:26.225 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:26.975 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:27.725 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:28.350 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:29.225 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:29.975 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:30.725 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:31.093 <I> [0] main: state change: [21] -> [8]
2012-06-11 15:21:39.847 <I> [0] main: state change: [8] -> [3]
2012-06-11 15:21:40.168 <I> [0] main: state change: [3] -> [4]
2012-06-11 15:21:40.977 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:41.727 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:42.478 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:43.228 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:43.978 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:44.728 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:45.478 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:46.228 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:46.979 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:47.729 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:48.479 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:49.229 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:49.979 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:50.730 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:51.480 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:52.230 <I> [0] main: state change: [21] -> [4]
2012-06-11 15:21:52.980 <I> [0] main: state change: [4] -> [21]
2012-06-11 15:21:53.174 <I> [0] main: state change: [21] -> [8]
```


Figure 3.2. Iris camera process logs showing calculation of time-on-task

The state change [x] -> [3] was used to signify the start of a presentation attempt. This state change, as referenced in Table 3.1, represented a change from the “Standby” state to the “Enter (Ready)” state. Any state change that resulted in a state ID of 8, or [x] -> [8], was used to signify the end of a successful capture because it represented a change resulting in the “Capture Complete” state. Any state change that resulted in a state ID of

13, or [x] -> [13], was used to signify a failed presentation attempt because it represented a change ending in the "Failed to Acquire" state.

The time-on-task was calculated by subtracting the time associated with the start of a presentation from the time associated with the end of a presentation, regardless of whether the presentation was a success or failure. A batch parser developed by graduate students at the International Center for Biometric Research (ICBR) performed this calculation automatically (Moore and Goe, 2013).

3.2.2 Tools Used for Data Collection

An Aoptix Insight Duo VM iris camera, manufactured by Aoptix Technologies, was used to capture iris images during the 2012 data collection exercise. This type of camera technology was designed as a stand-off iris device, which prompted users to stand in a capture area located approximately 1.5 meters from the camera. Table 3.2 presents the specifications of the iris camera (Aoptix Technologies, 2012).

Table 3.2. *Specifications of the iris camera used in the 2012 data collection*

Camera type	Stand-up
Camera height	1.47 meters
Stand-off distance	1.5-2.5 meters
Capture volume	.75 cubic meters
Iris illumination	820-860 nm of infrared light
Estimated capture time	4-6 seconds

It was noted that a failure occurred in the iris camera after Visit 1 of the data collection exercise. During the period between Visits 1 and 2, the iris camera began to shut down and reboot without the command of an operator. Eventually, the device shut down completely and was unable to reboot. When Aoptix Technologies was notified, the company sent an identical replacement device with the same specifications listed in Table 3.2. This replacement was not thought to affect timing or capture results, but it was considered during the quantitative analysis.

An issue with the iris camera's available memory also caused the deletion of many of the captured images during the 2012 data collection, particularly during Visits 1, 2 and 3. In a typical presentation attempt, the Aoptix Insight Duo captured both iris images and a face image. Video data were recorded by the device for further processing during the face detection phase of the capture. This video data took up a considerable amount of space and occasionally did not allow for the full capture of 40 iris images. When the maximum memory was reached, the camera purged the images that were already stored, causing many images to be permanently deleted. This problem was not identified until Visit 3, which caused a number of the images captured during Visits 1 and 2 to be deleted. Following Visit 3 and the issue's discovery, preventative action was taken to delete only the video data in the camera's memory after each presentation attempt, which allowed for the capture of all required images.

3.2.3 Capture Process for the 2012 Data Collection

The 2012 data collection exercise, which was the primary focus of the quantitative analysis, occurred in a basement room of the MGL building on the Purdue

University campus in West Lafayette, IN. As stated, the data used for this thesis were part of a larger biometric aging study that collected multiple modalities. Therefore, the iris camera was not the only biometric device with which subjects interacted. Figure 3.3 shows the floor plan in the MGL basement room used for this data collection exercise.

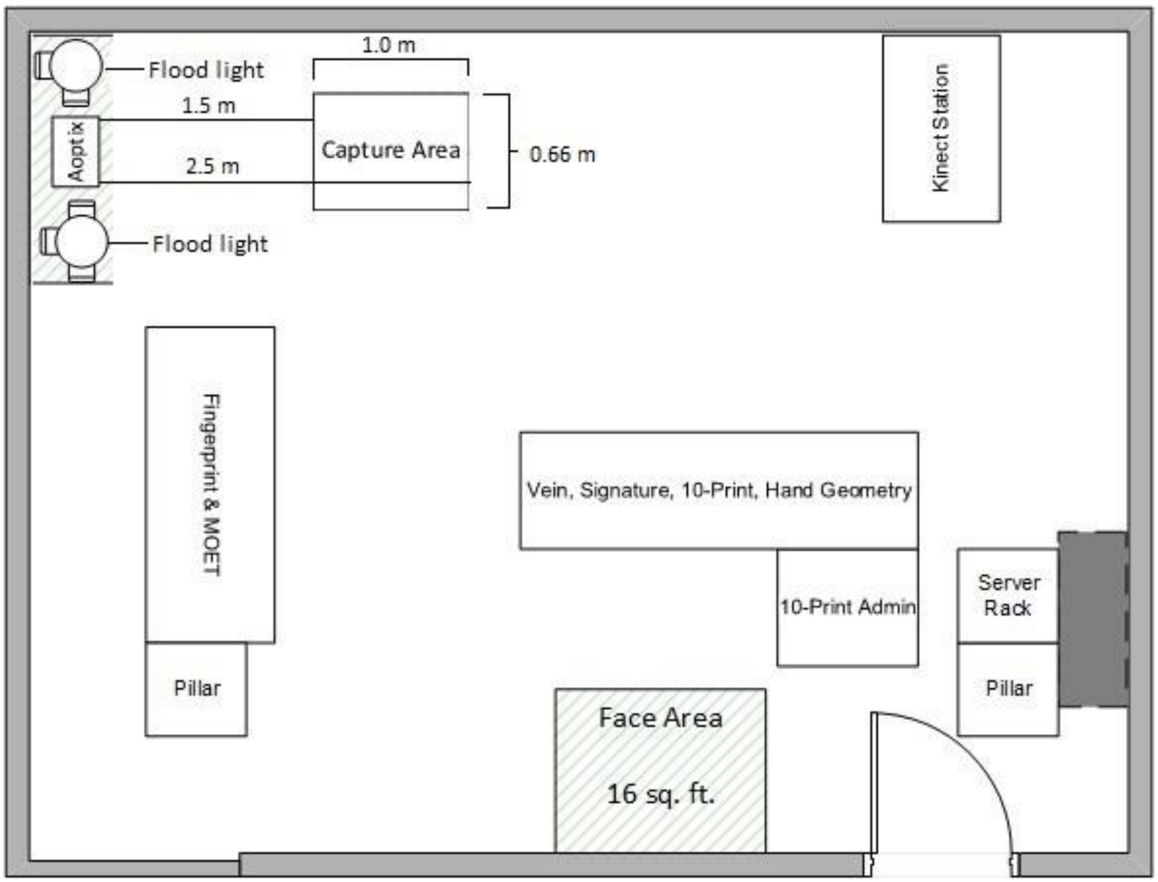


Figure 3.3. Floor plan of MGL basement used for data collection at Purdue University

The iris recognition station was set up to coincide with the capture area recommendations made by Aoptix Technologies. These recommendations stated that the capture area should be a 1 x 0.6-meter box, with the front of the capture area (i.e., the boundary closest to the camera) located one and a half meters away from the front of the iris camera and the back (i.e., the boundary furthest from the camera) located two and a half meters away. Red duct tape was used to signify the iris capture area to the subject.

The test designers incorrectly set up the capture area to be a four-square-foot box for Visit 1 of the 2012 data collection. However, the test designers noticed the incorrect capture area during the extended period caused by the device's failure. Based on the discussion of this thesis's proposal, the capture area was modified to fit the Aoptix-recommended 1 x 0.6-meter box, which caused a system environment change for the subjects and is explored further in Section 5.1.8.

Aoptix Technologies recommended that the light level of the capture area be set at 600 lux. The data collection exercise used additional floodlights to achieve this light level, shown in Figure 3.3. Upon positioning the floodlights, the test administrators validated that the capture area possessed the correct light level using a light meter before testing began for Visits 1 and 2. Figure 3.3 shows the dimensions of the iris capture area, in meters, as it was used in the 2012 data collection exercise.

After completing a fingerprint and skin characteristics station, each subject stepped into the capture area in front the Aoptix capture area, faced the camera, performed the first capture attempt and followed a loop marked on the floor until all successful captures had been completed or the subject had reached the maximum of 25 attempts. Figure 3.4 shows a flowchart for the capture process at the iris recognition station.

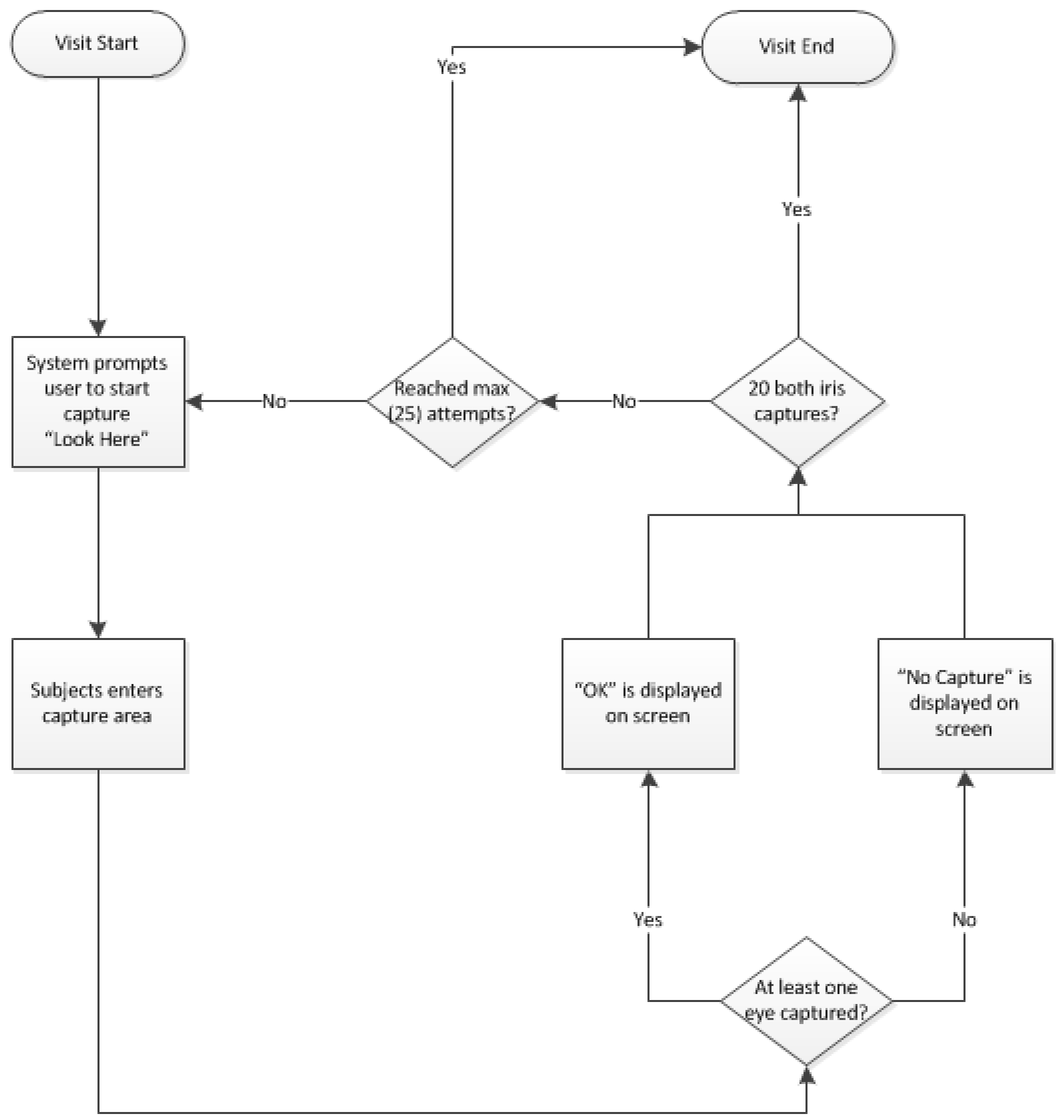


Figure 3.4. Flowchart of the capture process for the 2012 iris data collection

3.2.4 Sampling for Data Collections

Both the 2010 and 2012 data collection exercises were conducted in the same basement lab in the MGL building on Purdue University's campus. Similar methods were used to recruit subjects for both studies. All of the subjects were recruited using tear-away posters placed around the Purdue University campus. The tear-away portion of each poster contained a URL directing potential subjects to a scheduling site that allowed them to schedule an appointment. An example of this poster can be observed in Appendix D. No individual was denied the opportunity to participate in these studies, and any subject who completed the first visit of each data collection exercise became a part of the sample. The final sample after the first visit in 2010 contained 260 subjects, while the 2012 collection contained 115 subjects. Table 3.3 reports the resulting sample sizes for each data collection exercise, organized by visit.

Table 3.3. *Resulting sample sizes for each data collection*

	2010 Visits		2012 Visits								
	1	2	1	2	3	4	5	6	7	8	9
Device	Insight Duo SD		Insight Duo VM								
Males	123	111	53	32	27	22	18	17	17	17	2
Females	137	126	62	49	38	35	24	19	19	17	0
Total	260	237	115	81	65	57	42	36	36	34	2
Dropoff	-	8%	-	30%	43%	50%	63%	69%	69%	70%	98%

The drop-off rate noted for each visit in the table above is in relation to Visit 1 of the respective study. The 2010 data collection incurred a very low drop-off rate of only 8%, starting with 260 subjects and ending with 237. A considerable drop-off rate of 70% was observed during the 2012 data collection. Although a ninth visit was recorded, the eighth visit was considered the final visit because Visit 9 was performed only for retakes.

The drop-off in 2012 was theorized to occur for two reasons. First, the higher number of visits resulted in fewer subjects remaining motivated to complete the study. Second, the study was still occurring at the end of the Spring 2013 collegiate semester and extended into the summer, which resulted in a number of drop-offs due to students and faculty concluding the semester. The 2012 data collection started with 115 subjects at Visit 1 and ended with 34 subjects at Visit 8 (and two subjects at Visit 9).

The visits were not completed sequentially in either study. The start of a visit always overlapped with the end of the previous visit. This situation allowed data collection to be completed more efficiently and also allowed subjects to create appointments around their own schedule. Table 3.4 demonstrates how each visit overlapped with others and how long each visit lasted.

Table 3.4. *Time span of each visit in days*

Visit	Start	End	Span
2010 Visit 1	5/11/2010	7/8/2010	58 days
2010 Visit 2	5/18/2010	7/15/2010	58 days
2012 Visit 1	6/11/2012	4/15/2013	308 days
2012 Visit 2	3/29/2013	4/29/2013	31 days
2012 Visit 3	4/15/2013	4/22/2013	24 days
2012 Visit 4	4/22/2013	5/29/2013	37 days
2012 Visit 5	4/26/2013	6/5/2013	40 days
2012 Visit 6	5/6/2013	6/12/2013	37 days
2012 Visit 7	5/14/2013	6/18/2013	35 days

2012 Visit 8	5/24/2013	6/18/2013	25 days
2012 Visit 9	6/4/2013	6/18/2013	14 days

3.2.5 Metadata for the Data Collection Exercises

Both the 2010 and 2012 studies collected age and ethnicity data for all subjects. The test administrators prompted each subject to provide his or her age and ethnicity during the first visit of each study. Upon returning for additional visits, the test administrators verified that the age and ethnicity values remained current. The age and ethnicity data were not considered during the completion of this thesis. For detailed bar charts of the age and ethnicity distributions for each visit of both studies, see Appendix I.

3.2.6 Strategies for Reducing Drop-off During the 2012 Data Collection

A number of methods were used to prevent the drop-off from becoming significant in the 2012 data collection. Tear-away posters displayed around the Purdue University campus were used to advertise the data collection to students and faculty. (This tear-away poster can be observed in Appendix D.) A total of 115 subjects were recruited for the first visit of the 2012 data collection.

A long delay occurred between Visits 1 and 2 due to the occurrence of other studies. This period between Visits 1 and 2 was delayed further when the device failure occurred before Visit 2 could begin. Upon the device's replacement, an email was sent to the participants from Visit 1 to notify them that the data collection would continue. This email was personalized for each subject, and the general format can be observed in Appendix C.

In an attempt to reduce drop-offs, all subjects were asked to schedule the next visit after finishing any given visit. Subjects were asked if they had the ability to sign up for the next visit immediately after finishing a visit's collection. Subjects that were able to sign up for the next visit used a computer in the lab to schedule the appointment. However, many subjects were unaware of their schedules for the following weeks and opted out of scheduling an appointment immediately after the visit had ended. These subjects were told to schedule the next appointment when their schedules were known. It was assumed that a number of subjects who opted out ended up forgetting because drop-off still occurred.

A large drop-off was noticed near the conclusion of Visit 4, when the subject count barely surpassed 50 (compared to the initial 115). In response to this drop-off, nine subjects who had participated in Visit 3 but had not yet appeared for Visit 4 were sent reminder emails in an attempt to reduce drop-off. Appendix E contains a sample text used in these reminder emails.

Similar methods were used at the conclusion of Visit 5. The same email text shown in Appendix E was used to send reminder emails to 11 subjects who had participated in Visit 4 but had not yet appeared for Visit 5.

3.2.7 Analysis Methods Used for the Data Collection Exercises

After the data collection exercises were complete, the data were organized to begin the analysis of time-on-task trends, which are further discussed in Section 3.2.8. No data points were excluded during the quantitative analysis unless anomalies were identified. Exclusions that did occur in the data are noted in Chapter 4.

Before any statistical tests were performed, this study first examined the time-on-task trends to determine if any consistent increases or decreases occurred during each visit. These trends were explored in two ways. First, the analysis examined time-on-task trends between visits, considered inter-visit trends, which reported changes in subject time-on-task on a visit level. Upon completion of this inter-visit examination, the analysis also observed the time-on-task trends within a single visit, considered intra-visit trends. The analysis attempted to determine if any consistent increases and decreases in time-on-task occurred as subjects progressed through each attempt within a given visit. Statistical significance in the changes was evaluated upon the identification of consistent increases or decreases. Because a drop-off was noticed and because the subjects performed a varying number of attempts (20-25), the data points for each visit were not balanced. Additionally, all three metrics, time-on-task, matching performance (genuine scores) and image quality resulted in non-parametric distributions throughout all visits. Initially, an ANOVA tests were to be used; however, because the ANOVA assumes the distributions tested will be parametric, the determination of statistical significance relied on Kruskal-Wallis tests, with the standard significance level ($\alpha = .05$). Referencing Figure 3.5, the time-on-task distribution (upper left) is right-tailed. The matching performance distribution (upper right) shows a left tail with a spike to the right that represents self-matches. The image quality distribution (bottom) shows a left-tailed non-parametric histogram.

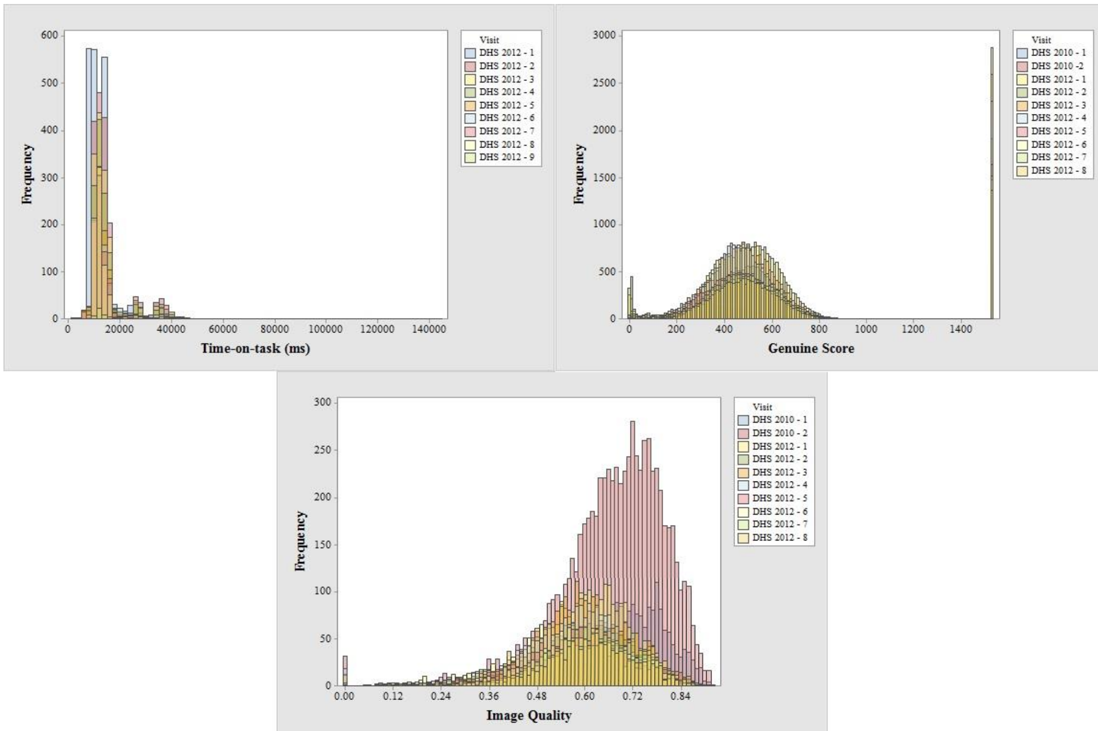


Figure 3.5. Histograms showing overall distributions for time-on-task (upper left), matching performance (upper right) and image quality (bottom)

The initial results of the qualitative survey analysis suggested that the matching performance and image quality were reliable metrics indicating habituation. Therefore, these metrics were also examined to supplement the time-on-task analysis. To obtain these metrics, post-processing of the iris images was performed on all of the collected images for matching performance using Neurotechnology’s Megamatcher and image quality using Aware’s IrisCheck. Data from a previous iris study that occurred in 2010 were also available for processing in terms of matching performance and image quality. The 2010 data collection included two visits and attempted to observe the effect of variant lighting on iris recognition. Twenty of the subjects who participated in the 2012 data collection had also participated in the 2010 study. Because this 2010 exercise had two visits that included multiple captures per visits, it was also suitable for examining habituation effects.

This supplemental analysis allowed for the comparison of matching performance and image quality between the 2010 and 2012 data collection exercises. However because the 2012 data collection captured only iris images with no real-time matching, the nature of the image capture process varied and caused the time-on-task to be inconsistently measured. Therefore, only the image quality and matching performance analyses considered these 2010 data.

The first visit for the 2010 data collection focused solely on enrolling and verifying subjects. This first visit progressed subjects through a single enrollment process that collected both the left and right irises and performed three verification processes for each iris. The verification process occurred separately for each iris, for a total of eight iris images collected at the completion of the first visit. The second visit of the 2010 exercise, however, verified each iris 15 times, for a total of 30 images per subject.

Similarly to time-on-task, both image quality and matching performance were examined for habituation trends throughout the visits from both studies prior to statistical tests being performed. However, due to improper image naming conventions after extraction from the iris camera, the attempt numbers were not recorded and did not allow intra-visit examination for image quality and matching performance.

Two iris cameras were used during the two data collection exercises for the supplemental analysis of image quality and matching performance. The camera used in 2010, an Aoptix VM, was almost identical to that used in 2012. The only difference between the two cameras was that the 2010 device could be mounted to a wall. However, the camera was actually mounted on a tripod for the purposes of the 2010 data collection. The specifications in Table 3.2 applied to this device.

3.2.8 Data Storage and Extraction

Prior to using the proposed methods to quantitatively analyze time-on-task, image quality and matching performance, the data were imported into a database specifically designed to house the variables. To store the captured iris images, the images and meta-data were uploaded into the main table used for image storage. Raw capture times were uploaded to a separate table linked to the main table that stored the iris images, which created a connection between the capture times and images. More importantly, this connection created a link between the capture times and the subjects who produced them.

A set of data was exported from the ICBR database for each quantitative analysis of time-on-task, image quality and matching performance according to the analysis being performed. This task required the export of different data for each analysis. Therefore, each export from the ICBR database was assigned a data run ID, creating the capability for exporting the exact same data for future studies and a means for repeatability.

All time-on-task data points, with the corresponding subject, visit and attempt IDs, were exported in a single data pull. This data pull was assigned the data run ID of 1118. Because the quality of a given image did not affect the quality of another image, all of the images from both data collection exercises were exported in a single data pull, with the corresponding subject and visit IDs, for the image quality analysis. This data pull was assigned the data run ID of 1120. Each visit was matched to itself for matching performance. Because the matching scores depended on the images contained in the dataset, each visit was exported separately, creating ten data pulls for the two data collection exercises. Table 3.5 provides a map of each data run used during the quantitative analysis.

Table 3.5. *Data runs used during the quantitative analysis*

Data Run ID	Data Run Description	Used in the Analysis of
1118	Timing Data Points – All 2012	Time-on-task
1120	Image Quality Data Points – All 2010 & 2012	Image Quality
1168	Iris Images – 2010 Visit 1	Matching Performance
1169	Iris Images – 2010 Visit 2	Matching Performance
1170	Iris Images – 2012 Visit 1	Matching Performance
1171	Iris Images – 2012 Visit 2	Matching Performance
1172	Iris Images – 2012 Visit 3	Matching Performance
1173	Iris Images – 2012 Visit 4	Matching Performance
1174	Iris Images – 2012 Visit 5	Matching Performance
1175	Iris Images – 2012 Visit 6	Matching Performance
1176	Iris Images – 2012 Visit 7	Matching Performance
1177	Iris Images – 2012 Visit 8	Matching Performance

3.3 Summary

The methodology used in this thesis provided the means with which to examine habituation and its effect on a biometric system. The execution of the qualitative habituation survey and quantitative data collection exercises attempted to gauge the existing definitions of habituation while determining the time-on-task metric's ability to indicate habituation. The following chapter reports the results of this analysis.

CHAPTER 4. RESULTS AND ANALYSIS

The purpose of this thesis was to document current definitions of habituation by examining the available literature and surveying experts in the biometric community. Not only did these efforts provide an expansive dataset of habituation research, they also allowed for the determination of current definition consistency among biometric experts, represented by the administered habituation survey. Furthermore, this thesis sought to identify an additional habituation indicator by examining the time-on-task metric, with a supplemental analysis of image quality and matching performance.

The procedures outlined in Chapter 3 were completed to fulfill these goals. The analyses were divided into two main sections: an analysis of the habituation survey and the quantitative analysis of data collected in 2010 and 2012. This thesis first reports the qualitative results and responses of the habituation survey. Upon completion of the qualitative analysis, the quantitative analysis results are reported by first presenting age and ethnicity data for the subject pools used during the 2010 and 2012 data collection exercises, and concludes with the time-on-task, image quality and matching performance analyses.

4.1 Results of the Habituation Survey

The habituation survey was distributed electronically to 30 biometric experts who possessed multiple years of experience in the biometric field. Appendix F shows the questions asked in the manner they were distributed to participants. The survey was designed and managed in *Qualtrics*, a survey software program provided to Purdue University. The responses to each question were analyzed independently for common themes to determine the existing perspectives on habituation among biometric experts. The responses to each question were examined for concepts shared by multiple experts to identify common themes. Only two responses to a given question had to share a concept to be considered a common theme.

This method of analyzing common themes began with Question 2 because Question 1 asked only for data on the respondents' experience. Of the 30 individuals invited to participate in this survey, 13 responded, resulting in a 43.33% response rate. The respondents were not forced to answer any question, and any blank response received a value of "N/A". Full responses to the survey can be observed in Appendix H.

Question 1 asked participants for their ages and years of experience in the biometric field, which are listed in Table 4.1.

Table 4.1. *List of respondents in the habituation survey*

Respondent	Age	Years of Experience
R1	61	29
R2	55	18

R3	40	19
R4	40	12
R5	31	10
R6	43	12
R7	30	8
R8	53	20
R9	28	4
R10	43	8
R11	62	25
R12	52	13
R13	38	15

Figure 4.1 and Figure 4.2 graphically display the distributions for age and years of experience, respectively.

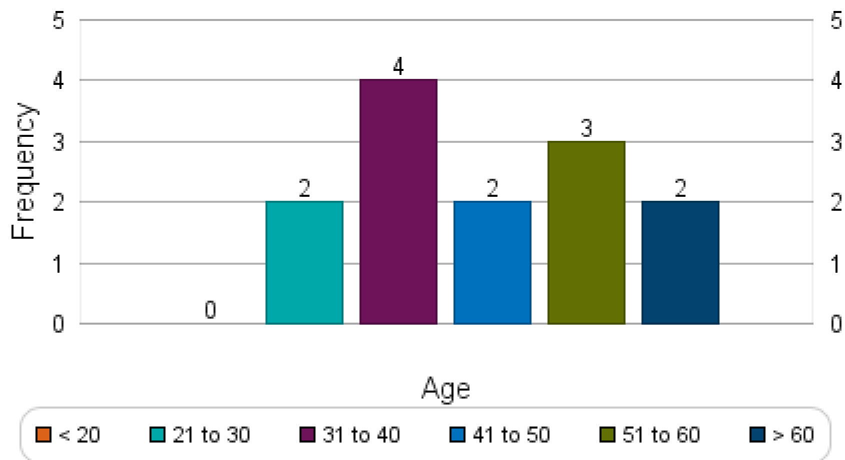


Figure 4.1. Bar chart of respondent age distribution for the habituation survey

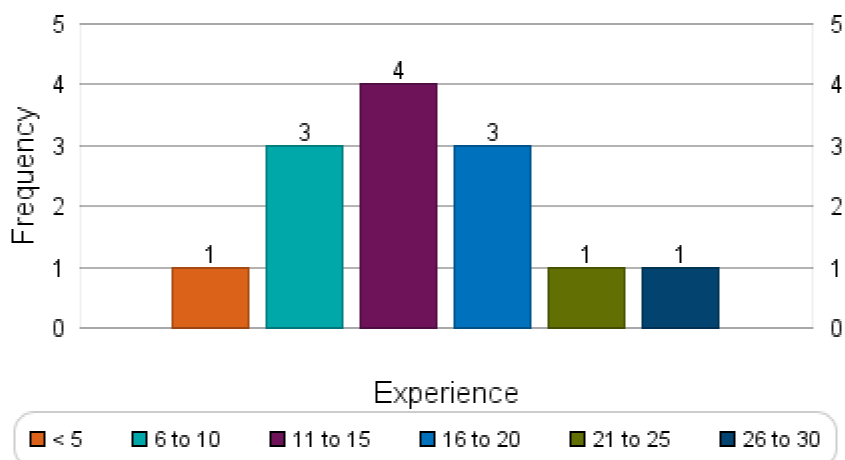


Figure 4.2. Bar chart of respondent years of experience for the habituation survey

Figure 4.1 shows that all respondents were above the age of 18 and therefore eligible to participate in accordance with the submitted IRB. Figure 4.2 indicates the level of expertise in this sample of respondents. Of the 13 respondents, nine had accumulated over 10 years of experience in biometrics. These results validated the level of knowledge and expertise in the received responses. The remainder of the survey analysis examines both the open-ended and closed portions of each question.

4.1.1 Question 2

Question 2 asked, “How would you define habituation in general?” All 13 respondents provided a response to this question, and four common themes were identified. Table 4.2 lists the themes and the number of times each theme was found throughout the responses to Question 2.

Table 4.2. *Themes identified in Question 2 of habituation survey*

	Description	Frequency	Present in Literature Review
Theme 1	Level of familiarity	8	✓
Theme 2	Repeated system use	4	✓
Theme 3	Less time required	3	
Theme 4	Accustomization to a process	3	✓

4.1.1.1 Theme 1 – Level of Familiarity

Habituation, defined as “a level of familiarity”, was the first theme discovered for this question. Eight of the received responses contained this theme.

R1 was the first respondent to directly mention a degree of familiarity, and defined habituation as:

> … Defn: degree of familiarity of a biometric capture subject with the biometric capture process NOTE 1:A biometric capture subject with substantial familiarity with the biometric capture process is referred to as a habituated capture subject…

R2 provided a similar definition referencing familiarity:

> Familiarity over time of a user/subject with the process of using a biometric system…

R8, R11 and R13 also provided a definition of habituation referencing familiarity in a biometric context:

> R8: being familiar with the use of biometric devices
>
> R11: In the context of biometrics: A process in which a subject becomes progressively more familiar with the use of a biometric collection device…
>
> R13: The process through which a subject/user gains familiarity with a biometric capture method in order to provide usable data.

R12 referenced improvements in familiarization when defining habituation:

> The efficiency increase of human-machine interaction through familiarization improvements based upon repetition...

While five of the last responses referenced biometrics, R3 and R7 provided responses that did not directly involve biometrics:

> R3: Becoming familiar with a process or stimulus which may or may not lead to complacency and accuracy of task execution.
>
> R7: Habituation is the process by which people become more familiar an efficient performing a particular task.

The above responses indicated that level of familiarity is a critical component in the definition of habituation.

4.1.1.2 Theme 2 – Repeated System Use

Dunning (2007) states that habituation occurs after continually using a biometric device. Similarly, in a social science context, habituation is defined as a decrease in a response to a repeated stimulus (Rankin et al., 2009).

R4 stated that habituation meant becoming accustomed through regular use:

> Habituation is where a user has become accustomed with a process through regular usage.

R5 defined habituation based on the repetitive nature of an activity:

> Habituation in the process of getting used to an activity due to the repetitive nature of activity…

R1 not only mentioned the repeated system use of the subject using the biometric device but also noted that the observation of another subject could cause habituation:

> …Habituation may be acquired through system use or observation of use by others…

The analysis of Theme 2 for Question 2 suggested that repeatedly using a biometric device can result in habituation and should be included as a definition component.

4.1.1.3 Theme 3 –Less Time Required

R5 was the first respondent to state that habituation could result in less time required to complete a capture process. Furthermore, R5 also stated that habituation could result in requiring less concentration:

> …results in requiring less concentration and time to complete the activity.

R12 made a similar statement but also stated that habituation could decrease the number of attempts required:

> …Habituation improvements include reduction in the number of attempts and/or the reduction in dwell time required for a successful capture event.

R7 stated that an increase in efficiency could be a result of habituation. This analysis interpreted efficiency as increased system throughput and a decrease in time-on-task. R7 stated:

> Habituation is the process by which people become more familiar an efficient performing a particular task.

The responses to this question provided enough evidence to suggest that habituation could result in a subject requiring less time to interact with a biometric device. Other metrics that could be affected by habituation were also referenced, such as a decrease in the number of attempts and a decrease in concentration. The results of this theme validated the motivation behind the analysis of the time-on-task metric, which is explored further in this thesis.

4.1.1.4 Theme 4 –Accustomization to a Process

R1 and R6 both responded by associating accustomization (to something) with habituation:

> R1: …make or become accustomed to something…
>
> R6: becoming accustomed or used to something

R4 also made a direct reference to becoming accustomed to a process. Furthermore, R4 also stated that becoming accustomed can occur through regular usage:

> Habituation is where a user has become accustomed with a process through regular usage.

Based on the received responses for this theme, the analysis suggested that the achievement of habituation in a biometric system involves becoming accustomed to the capture process. Becoming accustomed to a process is a key component in the definition of habituation.

4.1.1.5 Summary of Question 2

The goal of this question was to generally determine how the biometric community defined biometric habituation. Though some responses did not provide much insight, such as the response “some behavior that we don’t (want to) change”, the collection of common themes provided a means of interpreting an overall definition. Based on the results collected for Question 2, biometric habituation was defined as the process of a user becoming familiar with a biometric system by being accustomed to the capture process. Upon becoming familiar with the biometric system, the user can contribute improvements to the collection process, such as requiring less time for capture or fewer capture attempts. This definition was compiled from the collection of responses, which suggested that the responses were not comprehensive and that the definition was not universally understood throughout the biometric community.

4.1.2 Question 3

After analyzing the general definition of habituation among experts, the survey sought to focus on the specific effects of habituation on a biometric system. Therefore, Question 3 asked, “Do you think habituation has an effect on biometric systems?” One respondent did not provide a response to this portion of the question, but of the 12 responses received, all agreed that habituation does have an effect on biometric systems.

A follow-up question was also included: “If yes, why do you think it is important? If no, why not?” As with Question 2, the responses to the follow-up question were analyzed to discover common themes. Table 4.3 lists the themes present and the number of times each was discovered in the responses to Question 3.

Table 4.3. *Themes identified in Question 3 of habituation survey*

	Description	Frequency	Present in Literature Review
Theme 1	Affects System Performance	8	✓
Theme 2	Affects Human Behavior	5	✓

4.1.2.1 Theme 1 – Affects System Performance

R7 was the first respondent to state that habituation has a relationship with system performance. Furthermore, R7 stated that this relationship should be linear:

> The users level of habituation with the system should be a direct linear relationship with performance on the system.

R2 responded by referencing an improvement in system performance:

> Increases in habituation generally result in improved biometric system performance (both speed and accuracy) and reduction in user/system errors.

R12 made a similar statement, but did not directly mention "system performance":

> Improves througput and can reduce "failure to acquire" events

R5 and R6 responded that habituation positively affects system performance and noted the human interaction with a biometric system:

> R5: …This interaction process undergoes the habituation effect that can lead to lesser interaction time, higher quality of captured sample or both.
>
> R6: Habituation allows for efficient and accurate interaction with a biometric system.

R8 and R13 stated that habituation has a positive effect on system performance by mentioning a reduction in system error:

> R4: It is important because habituated users can reduce biometric system error rates due to their knowledge of how to use the system.
>
> R8: Habituation will reduce the chance of false rejection.
>
> R13: Very generally speaking, for some biometrics it is plausible that habituation will result in lower FTE rates and FNMRs.

In referencing Theme 1, these responses to Question 3 showed that habituation is important to a biometric system because it can affect the system's performance.

4.1.2.2 Theme 2 – Affects Human Behavior

R5 stated the importance of human behavior to habituation, but the response did not make much sense.

> Human's behaviour is a important factor, as well as habituation behavior.

R3 stated that habituation can cause a system's users to become relaxed, which will cause a change in human behavior:

> Habituation may lead to a relaxation in the execution of events associated with the interaction/donation of a biometric sample.

R1 stated that habituation causes a behavioral difference:

> … Leads to different behaviours during use Affected by frequency of use and time since last use Hursley 2013

R6 stated that habituation will allow for a change in interaction:

> Habituation allows for efficient and accurate interaction with a biometric system.

The responses submitted for this question, along with this theme's presence in the literature review, provided enough evidence to indicate habituation affects human behavior. This conclusion was considered a critical component of as the study because subjects would have to modify their behavior to achieve the improvements hypothesized for the upcoming quantitative data analysis.

4.1.2.3 Summary of Question 3

Question 3 was asked to determine the overall influence habituation has on a biometric system, including its influence on back-end processing and the human using the system. Both of the common themes identified, "affects system performance" and "affects human behavior", were considered critical in any application of a biometric system. Based on the interpreted responses, it was concluded that biometric habituation can affect the behavior of the human interacting with the system, which will affect the overall system performance. Although two separate themes were discovered for this question, both themes had an influence on the overall system performance. Therefore, the analysis of Question 3 concluded that the effect habituation can have on a biometric system was universally understood by the community.

4.1.3 Question 4

Question 4 asked, "Do you believe that acclimation and habituation are synonyms?" Nine of the respondents believed that "habituation" and "acclimation" are not synonyms. This response coincided with definitions of these terms in Kukula et al. (2007), who differentiate "acclimation" as a phase of adapting to an environment that occurs before habituation. Four of the respondents believed that "habituation" and "acclimation" are synonyms, which coincided with the use of these terms in Thompson (2009), who states that "acclimatization" has been used synonymously with "habituation".

A follow-up question was asked as a second part of Question 4: "If not, what is the difference?" The responses to the follow-up question did not share commonalities and did not result in a common theme for Question 4. The quotes below highlight each response differentiating acclimation and habituation.

4.1.3.1 Differences Between Habituation and Acclimation

R2, one of the respondents who submitted a response after selecting “Yes”, stated that the differences between these terms could be debated:

> Though I said yes, you could argue that acclimation is at the beginning of the learning curve (high slope area) whereas habituation extends beyond throughout the period of use.

R4 and R5 referenced adaption to an environment, although R5 stated that habituation implies a learning process:

> R4: Acclimation is adapting to an environment, habituation is becoming accustomed to a process.
>
> R5: Acclimation implies a change in inherent behavior or physiology of a human subject as it adapts to its environment. Habituation implies a learning process which changes only the behavior of the human subject.

R7 submitted a response similar to the difference between acclimation and habituation reported in Kukula et al. (2007):

> I believe acclimation has more to do with the user becoming familiar and comfortable with the system in terms of personal feelings and preference. Habituation deals more with repetition, practice and can be measured by speed, accuracy etc.

R13 stated that the difference existed in the formality of learning:

> Acclimation expresses the process that includes formal training as well. Habituation is more of an expression of user's state.

R9 differentiated acclimation from habituation through the level of difficulty each entails:

> Habituation is hard to change, but acclimation is not difficult.

R3 submitted a response differentiating habituation and acclimation according to the positive or negative effect on the biometric system:

> I see acllimation to be a positive process whereby a subject is becoming familiar with a device by adjusting to particular usability issues. Habituation is a negative process based on over-familiarity.

Finally, R6 was the only respondent to submit a response stating that habituation and acclimation are synonyms:

> Perhaps, in the context of biometric system, the 2 terms refer to the same concept

4.1.3.2 Summary of Question 4

Question 4 was asked to determine the overall perspective of the difference between acclimation and habituation, and arose from the differing opinions of Kukula et al. (2007) and Thompson (2009). In Kukula et al. (2007), the two terms are defined as two separate processes, while Thompson (2009) uses them as synonyms. Nine of the survey respondents did not believe that acclimation and habituation are synonyms, while four responses did. Based on the responses to the follow-up portion, it was interpreted that acclimation is defined as the physical change in a user's behavior, while habituation is the user's mental comprehension that the used behavior has either improved or worsened the capture process. This difference would suggest that during an acclimation phase, the changes in any observed metric would not be consistent until the user was able to distinguish the appropriate interaction with the device, resulting in either consistent improvement or consistent decreases in system performance.

Four respondents believed that the two terms were synonymous, and no common theme was discovered due to the variety of follow-up responses. Therefore, the differentiation between acclimation and habituation was considered not to be universally understood.

4.1.4 Question 5

The fifth question of this survey analyzed the influence a system administrator has on the progression of habituation to a biometric system. Question 5 asked, "Do you believe the influence of a system administrator, through feedback or initial instructions, affects habituation?" One respondent submitted the survey with this question left blank. Of the 12 received responses, only one response did not agree that feedback or initial instructions given by the system administrator had an effect on a user's habituation.

An additional question was included to supplement the belief that a system administrator can influence the progression of habituation. The follow-up question asked, "If so, in what ways does such influence affect habituation? If not, why not?" Two common themes were identified and are listed in Table 4.4.

Table 4.4. *Themes found in Question 5 of the habituation survey*

	Description	Frequency	Present in Literature Review
Theme 1	Instruction/Feedback Type Affects Habituation Time	6	✓
Theme 2	Affects Human Behavior/Performance	2	✓

4.1.4.1 Theme 1 – Instruction/Feedback Type Affects Habituation Time

R3 stated that the influence a system administrator has on habituation depends on how structured the instructions and feedback are. If a biometric users hears the same instructions repeatedly, the habituation effect will be more noticeable:

> … the more 'scripted' the feedback the larger the effect. A good analogy is the emergency instructions of aircraft - do frequent flyers actually take this in everytime?

R2, R4, R5, R8 and R13 stated that the quality of instruction and feedback can accelerate habituation progression:

> R2: Good instructions can accelerate habituation.
>
> R4: It can speed up habituation as may help users learn best approaches to the process faster.

> R5: The quality of feedback provided by the administrator has an impact on the time to get habituated…
>
> Initial instruction by a system admin will reduce the time (or duration) of habituation.
>
> R13: Well-constructed advice from an administrator can shorten the time in which the user becomes habituated…

Based on the literature and the received responses, biometric experts agreed that good initial instructions/feedback can accelerate the time it takes to become habituated. Additionally, one response even stated that proper instructions can strengthen the level of habituation achievable by a system user.

4.1.4.2 Theme 2 – Affects Human Behavior/Performance

In contrast to Theme 1, which stated that good initial instructions can accelerate habituation, this theme encompassed the behavioral differences that result from a system administrator's instructions. R7 referenced the direct effect a system administrator has on human behavior:

> It has a direct impact on the user's behavior and overall performance. they are no longer thinking on their own

R9 made a more detailed statement about the change in behavior for a specific modality:

> For example, in a fingerprint recognition system, a admin may ask users to press sensor very hard, those users habituation can be affect.

These responses provided enough information to conclude that a system administrator can influence habituation through human behavior and performance. This conclusion is based not only on Theme 2 but also on Theme 1, which stated that the system administrator might influence habituation by accelerating it through good initial instructions. In this context, a subject must vary the way he or she interacts with the system before the proper interaction is learned to accelerate habituation.

4.1.4.3 Summary of Question 5

This question was asked to determine whether a system administrator, or the human controlling the system, has a significant influence on the progression of habituation in a human using the system and whether that acceleration occurs through initial instructions or feedback. This question was particularly important because it is the system administrator's responsibility to facilitate prompt use or essentially act as the stimulus when a system device is not prompting the human to use it, as defined in Rankin et al. (2009). Additionally, as reported in Theofanos et al. (2006), feedback to the user yields an increase in fingerprint image quality.

The responses received for this question showed that respondents had varying opinions on a system administrator's influence on habituation in a biometric system. Some respondents highlighted the effect on the overall progression of habituation, while others focused on the different behaviors a system administrator could influence. Because of this variation, the received responses showed inconsistency related to system administrator influence and habituation.

The analysis concluded that a system administrator's instructions and feedback can influence user behavior and, depending on the quality of the instructions and feedback, the time it takes a user to habituate.

4.1.5 Question 6

The sixth question asked in this survey was, "Do you believe there are different phases of habituation that can occur over time?" Two respondents did not submit responses to this question. Of the 11 received responses, nine believed that habituation occurs in phases, which suggested a consensus among the respondents in believing that habituation occurs in phases over time.

An additional follow-up question was asked: "How would you differentiate the different phases?" Each response contained varying opinions on the differentiation of habituation levels, resulting in no common themes. Each response describing the differentiation of phases is shown below.

4.1.5.1 Differentiation of Phases

R13 stated that habituation occurs in only two phases, with the transition between phases occurring when the user's techniques become elementary:

> By the before- and after- periods of the point at which the user's methodology can be considered to have become, in a manner of speaking, innate.

R7 also submitted a response distinguishing two phases and mentioned that the transition between the phases occurs when the level of improvement becomes stable:

> At a minimum, I believe there are 2 phases. the first were the user's habituation level is rapidly increasing to a certain acceptable level and then the speed of habituation levels off into a flat or minimal improvement phase…

R12 stated that three levels of habituation exist, starting with no habituation:

> Unhabituated - no knowledge of the device, its operation or expected outcomes; Novice - Limited knowledge of, or experience with the device or expected outcomes; Habituated - Experienced user of the device that consistantly achieves the expected outcome

R4 also responded with three phases but differentiated the phases temporally:

> Use category labels such as early, medium, long-term habituation.

R2 responded with three phases as well. Unlike R12 and R4, however, R2 differentiated the final phase in a negative context because the user of a biometric device will have become complacent:

> Initial (learning), confident usage, sloppy usage

R5 stated that four phases occur, each focusing on a level of comprehension of the applied information:

> …Understanding the information, Contextualizing the information, Internalizing the information, Maintaining the information

4.1.5.2 Summary of Question 6

In relation to Question 5, which sought to determine the difference between acclimation and habituation, or possible phases of the habituation process, Question 6 attempted to identify whether different phases occur during the habituation process. Nine respondents believed that multiple phases of habituation occur throughout the process, but no common themes were discovered. Additionally, three follow-up responses were discarded because they stated “Not sure”. The analysis of the follow-up responses indicated a disparity because respondents did not share opinions on the levels of habituation through which a user can progress.

Based on the variety of responses, no common themes were noticed and an inconsistency among the responses of biometric experts was suggested.

4.1.6 Question 7

Question 7 asked, “Do you believe habituation affects the quality of a given sample?” Two participants submitted the survey with the first portion of the question blank. The 11 participants that did respond to this portion of the question agreed that habituation affects the quality of a given sample.

To supplement the results of the first question, an additional question was included: “If so, in what ways do you think habituation affects the quality? If not, why not?” One respondent who did not answer the first portion of Question 7 submitted a response to the follow-up question, leading to the analysis of 12 responses.

Only one common theme was discovered in the responses to this question: “higher levels of habituation cause higher quality” was present in ten responses. Theofanos et al. (2007) demonstrate this theme in a fingerprint recognition device. In their study, each subject presents his or her fingerprint to the device multiple times per visit and returns for two visits. Upon returning for a second visit, the subjects’ fingerprint image quality is shown to improve.

R2, R4, R5, R6, R11 and R12 all made mention of an increase in quality due to corrected presentations and interactions from the habituated user. They responded as follows:

> R2: …results in a higher quality sample being captured.
>
> R4: Habituated users should on average present higher quality samples, as they have become accustomed as to how best use the system.
>
> R5: It affects quality because it reduces the ambiguity of how a user should interact with the sensor, as well as how to compensate for any extraneous factors that can affect quality (like dirt on finger, wearing glasses, etc)
>
> R6: It could - it can diminish poor quality captures due to poor presentation…
>
> R11: …capable of making more uniform presentation to the device and thereby producing higher quality samples with lower variance…
>
> R12: The user understands what is expected during the presentation and thus can often provide the sample within the "sweet spot" of the device versus an unhabituated user that often will provide a sample closer to the edge of the tolerance level of the device

R9 made a statement that was difficult to comprehend, but it was interpreted as a change in quality due to a change in presentation:

> In fingerprint recognition system, the angle, force or duration when ones finger touches sensor.

R3 also submitted responses stating that quality is affected by presentations and interactions. R3’s response was interpreted as saying that as habituation occurs, the user’s interactions can become lazy, causing presentations to become complacent and decreasing the quality of a given sample. R3 responded:

> R3: Incorrect/complacent presentation towards a capture device

Without mentioning interactions or presentations, R7 and R8 both stated generally that higher habituation levels cause higher quality:

> R7: higher habituation should result in higher quality.
>
> R8: As a user is more habituated to a device, the quality of sample will become better.

4.1.6.1 Summary of Question 7

All of the respondents agreed that habituation affects that quality of a biometric sample. Additionally, they agreed that the quality of a given sample is affected by the quality of interaction and presentation to the biometric device, which is likely to change as a user progresses towards habituation. This result suggested that habituation’s effect on biometric sample quality is universally understood in the biometric community. For the most part, respondents believed this effect should improve sample quality. However, if a habituated user becomes too relaxed, this relaxation may cause an incorrect/complacent interaction or presentation, which can decrease sample quality. The responses provided enough evidence to indicate that habituation can affect the quality of a given sample through user presentation and interaction.

4.1.7 Question 8

Question 8 of this survey asked, “Do you believe habituation directly affects the performance of a given sample?” All ten respondents that answered this question believed that habituation affects the performance of a given biometric sample.

A follow-up question was asked to supplement this consensus: “If so, in what ways do you think habituation affects the performance? If not, why not?” Two common themes were identified when analyzing the responses to this question and are listed in Table 4.5.

Table 4.5. *Themes found in Question 8 of habituation survey*

	Description	Frequency	Present in Literature Review
Theme 1	Performance is Correlated to Quality	6	✓
Theme 2	Levels of Habituation Cause Varied Presentations	3	✓

4.1.7.1 Theme 1 – Performance is Correlated to Quality

The consensus of the previous question, Question 7, stated that habituation affects sample quality through interaction and presentation. Multiple authors, particularly Young and Elliott (2007), Brockly and Elliott (2011), and Grother et al. (2007), believe that sample quality can directly affect system performance, with higher sample quality typically improving system performance and lower quality samples causing degradation. This concept was echoed in the survey responses given below.

R2 first mentioned a correlation between sample quality and system performance:

> Yes, as performance is usually correlated with sample quality.

R4, R5 and R8 provided similar responses relating system performance and sample quality:

> R4: Habituated users should be able to present higher quality samples and interact with the process better, on average, than non-habuitated users unfamiliar with the process.
>
> R5: Habituation has an impact on sample quality, which affects how much the sample contributes to FTA, FAR and FRR of the system.
>
> R8: More habituation -> Better sample quality -> Less FRR

R3 and R11 referenced Question 7 by answering with “See definition” and “Same as prior answer”, respectively, to state the correlation between system performance and sample quality made in previous responses to Question 7. These respondents had stated in Question 7:

> R3: Incorrect/complacent presentation towards a capture device
>
> R11: … capable of making more uniform presentation to the device and thereby producing higher quality samples with lower variance…

The results from Question 7 already suggested that habituation affects sample quality. Based on the responses to Questions 7 and 8 and statements made in Young et al. (2007) and Brockly et al. (2011), enough data were present to conclude that habituation affects system performance through its correlation to sample quality.

4.1.7.2 Theme 2 – Levels of Habituation Cause Varied Presentations

The responses received for this question were similar to those received for Question 7 in that they indicated habituation affects quality or performance through users' correct/incorrect presentations. R4, R6 and R7 all stated that habituation affects system performance through a change in a user's presentations to a biometric device. R4 and R6 submitted similar responses to Question 7. R4, R6 and R7 stated:

> R4: Habituated users should be able to present higher quality samples and interact with the process better…
>
> R6: It could - poor presentation (nonfrontal gaze or capture of tip of fingerprint) will result in low performance.
>
> R7: higher habituation should be high performance because the system is being used as it is inteded to.

Similar responses to Question 7 indicated that improvements in sample quality result from proper presentation to a biometric device. Similar responses received for

Question 8 provided enough evidence to suggest that habituation affects system performance by causing a change in user presentations to a biometric device. It was evident that respondents agreed that habituation increases the amount of correct presentations, resulting in improved system performance.

4.1.7.3 Summary of Question 8

Similarly to Question 7, which examined experts' opinions on the relationship between habituation and image quality, Question 8 asked respondents to determine habituation's relationship with system performance to verify statements made in the literature (Young et al., 2007; Brockly et al., 2011; Grother et al., 2007). When analyzing the 11 responses received for the second portion of this question, two common themes were discovered: "performance is correlated with quality" and "higher levels of habituation can cause incorrect/correct presentations". Although Question 8 yielded two separate themes, both led to the same result, a change in system performance due to habituation. Therefore, the results of this question were interpreted as stating that habituation can change the way a user interacts with a biometric device, which can cause increases and decreases in both image quality and matching performance. No disparity was noticed among experts when relating habituation to system performance.

4.1.8 Question 9

The ninth question of this survey asked, “Dishabituation is defined as "the restoration of a habituated response by extraneous stimulation." In biometric terms, your habituated presentation changes when a different stimulus is used. Do you believe that “dishabituation” occurs?” Six respondents believed that dishabituation exist and two did not, suggesting a consensus leaning towards the belief that it exists. Five respondents did not submit responses.

An additional question was asked to supplement the results of the first portion of Question 9: “If so, what do you believe causes dishabituation?” All eight respondents to the first question also answered the second question. Two common themes were discovered and are listed in Table 4.6.

Table 4.6. *Themes found in Question 9 of habituation survey*

	Description	Frequency	Present in Literature Review
Theme 1	Caused by Changes in User Interface/Environment	3	✓
Theme 2	Caused by Lack of Repeated Use	3	✓

4.1.8.1 Theme 1 – Changes in User Interface/Environment

R2 and R3 made direct responses indicating changes in user interface, such as a change in biometric sensors, and changes in environment as possible causes of dishabituation. Their statements were as follows:

> R2: Changes in user interface, environment, etc.
>
> R3: I wanted to answer 'I'm not sure' – I guess a change in UI/instructions/feedback may improve things

R8 directly referenced both a change in sensors and the time between device uses as possible causes of dishabituation:

> The time elapsed since the last usage. Use of different types of sensors (ex: change from an area type sensor to a swipe type sensor)

Based on these responses and the definition of dishabituation in the literature (Thompson, 2009), enough evidence was provided to suggest that the dishabituation of a user to a biometric system can be caused by a change in the interface and/or environment.

4.1.8.2 Theme 2 – Caused by Lack of Repeated Use

Rankin et al. (2009) states that dishabituation can be a function of elapsed time between each given stimulus. If a stimulus is withheld for extended periods or is not repeated regularly, these breaks may affect the way a user makes a presentation, causing dishabituation to occur. R5 repeated this statement by referencing a lack of repeated tasks:

> Dishabituation can occur over time due to the lack of repeating the tasks involved in completing an activity to which you were earlier habituated…

R7 and R8 also referenced a lack of repeated interaction:

> Decreased level of regular interaction, or long gaps of no interaction.
>
> The time elapsed since the last usage. Use of different types of sensors (ex: change from an area type sensor to a swipe type sensor)

Based on the definition of dishabituation in the literature (Thompson, 2009) and its recurrence in the respondents' answers, it was evident that the dishabituation of a user to a biometric system can be caused by a lack of repeated use or an extended period between each use.

4.1.8.3 Summary of Question 9

Dishabituation is a commonly used term in social science literature, specifically in Rankin et al. (2009) and Thompson et al. (2009). However, no mention of dishabituation is made in biometric literature. Question 9 was asked to determine if biometric experts were familiar with the term. Six respondents stated the belief that dishabituation does occur in a biometric system. The follow-up responses received for Question 9 provided enough evidence to suggest that dishabituation can occur and it is caused by changes in the user environment and/or a lack of repeated device use.

Because five respondents did not submit answers to this question and two did not believe dishabituation occurs, a disparity was still noted, and the experts' perspectives were considered inconsistent.

4.1.9 Question 10

Question 10 asked, "Would the classification of levels of habituation be beneficial to the implementation of a biometric system, either in a lab environment or corporate setting?" Three respondents did not submit a response to this question and eight agreed that benefits would exist in the use o f habituation levels.

An additional question was included: "If so, explain the practicality of a numerical classification system. (For example, a level 1 habituated user is a novice, while a level 5 habituated user is the most experienced)". After analyzing this question for common themes, the notion that classifying levels of habituation would "allow for proper administrative assistance/feedback" was the only theme discovered, and it was present in four responses.

R2, R5, R7 and R8 submitted responses stating that the classification of levels would be beneficial for proper assistance or feedback:

> R2: Most utility would be in planning for administrative assistance to users based on their habituation level.
>
> R5: Such a system can be used to determine exactly what type of feedback needs to be provided to the user (more for a less habituated user). This would also be useful in determining what type of remediation processes to use in case of an error that occurs (analogous to level 1 vs. level 3 technical support)

> R7: Just as in rapid tolling on the highway or express lines at the store, segmenting out level 5 biometric users who need little to no admin interaction will be much quicker on their own instead of lumping them in with level 1 users. Furthermore, studying level 1 users for faults or problems can lead to better user education.

4.1.9.1 Summary of Question 10

Like Question 6, which explored habituation phases, associating levels of habituation with biometric users could provide an efficient means of separating users to allow for an appropriate level of feedback and instruction, which could improve throughput because treating each user as a first-time user would be unnecessary.

Only one common theme was discovered and stated that the classification of different habituation levels would allow for proper instructions and feedback. Three of the eight responses contained this theme. The remaining five responses did not share any similarities with other responses. Upon analysis of this question, the responses indicated that differentiating levels of habituation could allow for an appropriate level of instruction and feedback to be provided to biometric users.

Based on the varying follow-up responses and the number of respondents who did not answer, the benefit of using habituation levels was not considered universally understood among the community.

4.1.10 Question 11

Question 11 of this survey instructed the respondents to rate the importance of factors that may cause habituation: “Many factors exist that may affect habituation in a subject. Some of these factors may be more influential on habituation than others. Please rate the following factor's influence on habituation (with 0 being "not influential at all" and 10 being "very influential)”. This question presented a list of factors and allowed the respondent to rate each factor from zero to ten, with zero being “the least influential factor” and ten being “the most influential factor”. Table 4.7 shows the listed factors and the total responses for each factor, the mean influence score and the standard deviation for each score, sorted from highest rated factor to lowest rated factor. Figure 4.8 visually displays these results in a bar chart.

Table 4.7. *Factors in responses to Question 11*

Factor	Total Responses	Mean Score	Standard Dev.
Number of interactions per visit	9	9.33	1.41
Number of attempts per visit	9	9.33	1.73
Training given to subject	9	9.22	1.79
Test administrator feedback	9	8.89	1.45
Number of visits device is used	9	8.78	1.99
Length of time between each visit	9	8.67	1.73
Complexity of device interaction	9	8.67	2.40
Subject IQ	9	7.00	3.81
Time-on-task	9	6.78	3.07
Change of environment	8	6.75	2.60

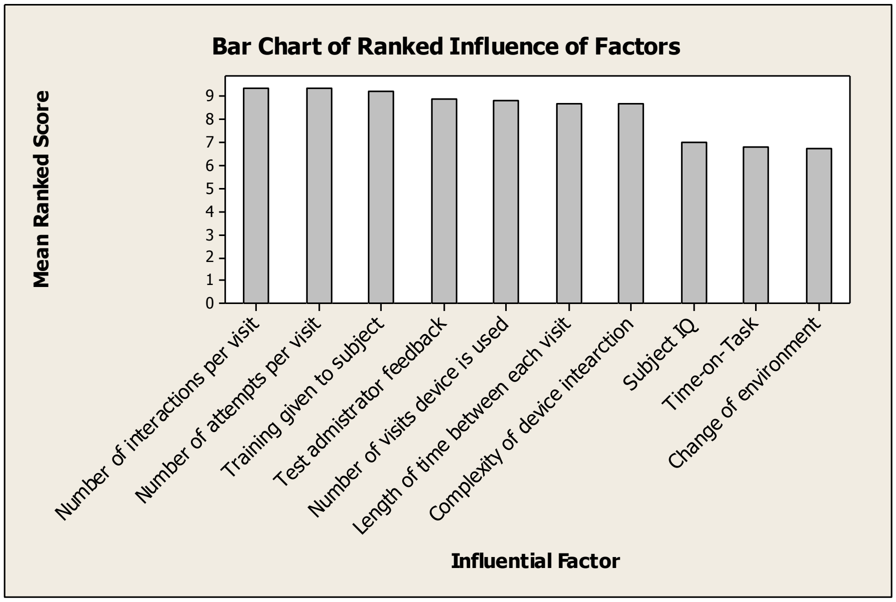


Figure 4.3. Bar chart of mean ranked scores for influential factors

These results showed that the experts' consensus on the most influential factors included number of interactions per visit, number of attempts per visit and training given to subject. Those that closely followed were test administrator feedback, number of visits device is used, length of time between uses and complexity of device interaction. Time-on-task was ranked the second lowest influential factor, which appeared to contradict the purpose of this study. However, time-on-task was included in the wrong context in this question. During the development of the survey, the inclusion was meant to determine if time-on-task is a beneficial indicator of habituation. However, the question asked respondents to rank these factors according to how influential they were in progressing user habituation and not how useful they were as indicators. Based on the results for Question 11, it was evident that habituation is a function of the frequency of use and instruction.

4.1.11 Question 12

The final question of this survey asked, “If there was any biometric modality that you based the above results on, please provide the name of that modality”. This question was left open-ended and did not force a response. Only four responses were received for this question and are listed in Table 4.8.

Table 4.8. *Responses received for Question 12*

Respondent	Response
R4	Signature
R5	Fingerprint, face and iris
R7	Fingerprint
R8	Fingerprint

No direct conclusions were made as to what modality was most commonly perceived by biometric experts concerning habituation.

Question 12 was the last question examined for this survey. Prior to analyzing the question and based on the variety of responses received for the previous questions, the analysis of the survey began to lead away from the possibility of developing a comprehensive definition of all biometric modalities and applications. The modalities provided for this question further emphasized this interpretation. Upon completion of this question's analysis, it was concluded that habituation cannot be concretely defined for the entire field of biometrics. Rather, it can only be generally defined. However, defining specific criteria with which to identify habituation in such applications will be beneficial to long-term implementations.

4.1.12 Conclusions of the Habituation Survey

The goal of this survey was not only to determine the overall perception of habituation among biometric experts but also to show that habituation was not uniformly understood. Excluding Questions 1, 11 and 12, each question asked the respondent to expand on a specific concept of habituation determined by the previous literature review. This method allowed for the discovery of common themes present in the responses received for each question. The analysis considered a common theme when the foundation of a respondent's answer shared the perception of another respondent. Each question, with the exception of Questions 6 and 7, resulted in the discovery of at least one common theme, with some containing multiple themes.

When providing a definition, the respondents suggested that biometric habituation is a level of familiarity with a device attained by accustoming the user to the capture process through repeated system use. Habituation could result in users requiring less time to properly present to a device. This definition validated this thesis's hypothesis that the time-on-task metric is a valid indicator of habituation. Additionally, the survey analysis suggested that habituation could affect the behavior of a human user presenting to the biometric device, which can affect image quality by influencing matching performance.

Based on received responses, a number of items identified in this survey were concluded to affect the progression of habituation prior to a user's habituation to a biometric device, including the quality of training and feedback provided, number of interactions with the device during a given visit, number of visits, length of time between visits and complexity of the capture process. Dishabituation can occur when the user experiences a change in capture environment or does not use the device for an extended period of time. The user begins to habituate to the new capture environment or must rehabituate due to a lack of repeated use, resulting in dishabituation.

The respondents did not submit universal responses to a number of questions, specifically the questions that expanded on the phases and levels of habituation a user could achieve. Because this thesis hypothesized that the identification of habituation levels could provide a refined level of instruction and feedback, the responses showed that the habituation phases, or the differentiation between acclimation and habituation, were not well understood. A number of respondents did not agree on any beneficial outcomes of identifying habituation levels. With the variety of responses received for these questions and the survey in general, the analysis concluded that the biometric community does not universally understand the concept of habituation.

This survey analysis concluded that the inconceivable number of ways in which integrators can implement a biometric device resulted in the inconsistencies observed in the survey responses. Therefore, habituation could be comprehensively defined only for the specific application of a biometric device and in the case of an extended implementation, and defining criteria to indicate user habituation would be beneficial.

4.2 Results of Data Collection Analyses

This quantitative section was initially meant to be used to refine current definitions of habituation by exploring the time-on-task metric. However, based on the results of the survey analysis, it was concluded that habituation could be specifically defined only for the device and its application. Therefore, this quantitative analysis acted as a means with which to characterize habituation in the context of the data collection exercises reviewed in Chapter 3. Instead of redefining habituation, the analysis attempted to observe habituation trends according to time-on-task, image quality and matching performance. The quantitative habituation analysis was divided into the following sections: analysis of time-on-task, analysis of image quality and analysis of matching performance.

The examination of time-on-task included only the timing data collected in the 2012 exercise due to an absence of timing data collected in the 2010 study. Because images of the same subjects were available from both the 2010 and 2012 studies, processing of both image quality and matching performance was performed on this subset of images. Similar methods were used to report the results to maintain a connection between the analyses of time-on-task and image quality/matching performance.

4.2.1 Time-on-task Analysis

An initial examination of the collected data was required to properly characterize habituation using the time-on-task metric. Using the timing data collected only during the 2012 study, habituation trends were explored by observing increases and decreases in the time-on-task metric, with decreases being considered a beneficial effect. This examination was completed throughout Visits 1-9 for inter-visit habituation and completed within each visit throughout the required attempts for intra-visit habituation.

All timing data were uploaded to the BSPA Labs database prior to analysis. To make the results reported in this thesis repeatable, a data run ID used by the ICBR database suite was assigned to the data exported for the time-on-task exploration and analysis. This data run ID was 1118. Table 4.9 reports an overview of these data.

Table 4.9. *Overview of timing data for 2012 data collection*

			Time Span from Previous Visit (days)			Time-on-task (ms)		
Visit	# of Subjects	# of Time Data Points	Min	Mean	Max	Min	Mean	Max
1	103	2340	-	-	-	1298	13170	143938
2	80	1842	0	239	301	1369	15120	144389
3	65	1482	3	12	32	8154	14514	41188
4	57	1310	4	12	26	7965	14714	65207
5	42	927	4	9	30	4092	13175	46155
6	36	805	5	9	29	8584	13545	46823
7	36	797	4	7	22	3185	12968	38989
8	34	735	1	7	15	7187	12566	38826
9	2	42	7	7	7	9339	12442	16466

The drop-off rate in this table matches the drop-off rate reported in Section 3.2.4, which was calculated based on the number of consent forms received. However, due to improper data collection and extraction from the Aoptix device, the timing data for 12 subjects from Visit 1 and one subject from Visit 2 were purged without an opportunity for recovery, resulting in the mismatch visible in the above table. The data collectors did not detect this deletion until the entire data collection exercise had been completed.

As detailed in Chapter 3, a device failure occurred between Visits 1 and 2. The replacement of the failed device caused an extended delay between the end of Visit 1 and the start of Visit 2. Because this new device was the same model as the previous device, any timing differences due to system processes were considered minimal. However, due to the extended period between Visits 1 and 2, five new subjects were recruited after the device failure, which extended the span of Visit 1 by more than 200 days, for a total span of 308 days.

This exploration began with the examination of changes in the time-on-task metric throughout visits, denoted as inter-visit habituation. The mean time-on-tasks for each visit were compared to those for all other visits. Figure 4.4 graphs the distribution of each visit as a boxplot.

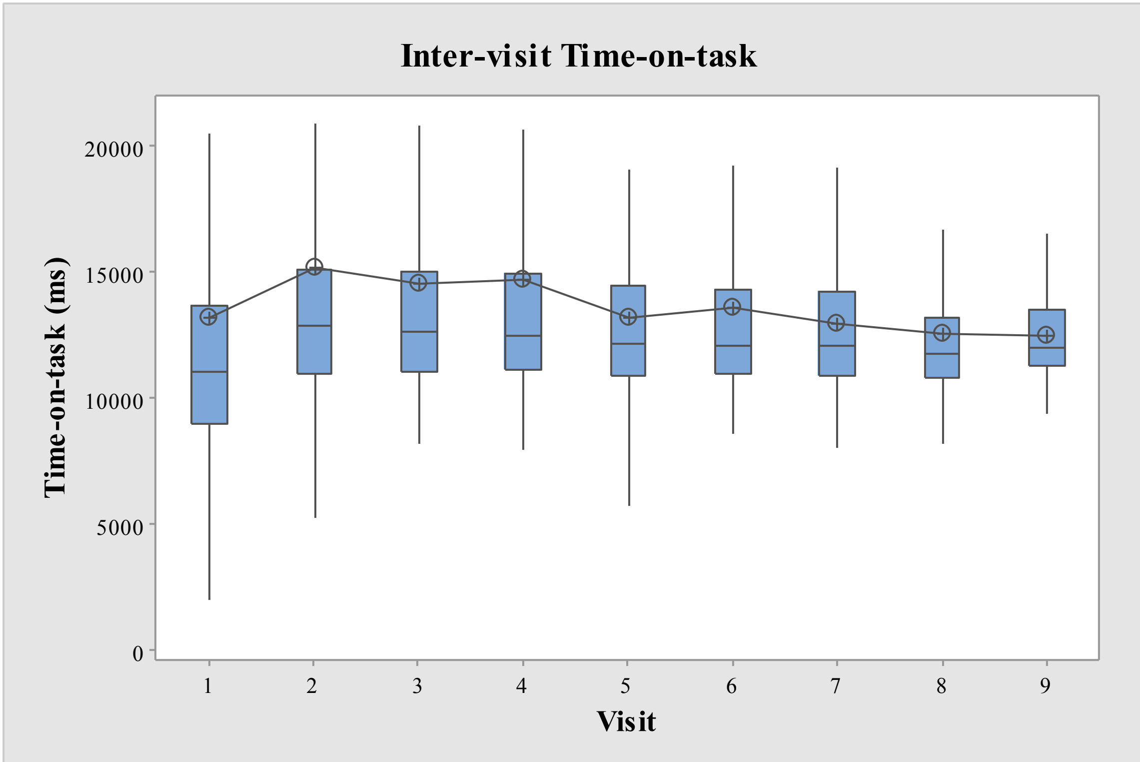


Figure 4.4. Box plot of inter-visit time-on-task distributions for all subjects

An initial analysis of this plot indicated an increase in time-on-task after Visit 1 extending into Visit 2. A Kruskal-Wallis test confirmed that this increase was significant ($N = 2241$, $H = 17.70$, $df = 1$, $p < .001$). The spike in time-on-task after Visit 1 was initially attributed to the device failure outlined in Chapter 3, which caused a change in the environment and an extended period between the two visits. To further explore the increase after Visit 1, the analysis examined outlier populations throughout the visits. *Figure 4.5* shows a scatter plot of the time-on-task data points for Visits 1-9.

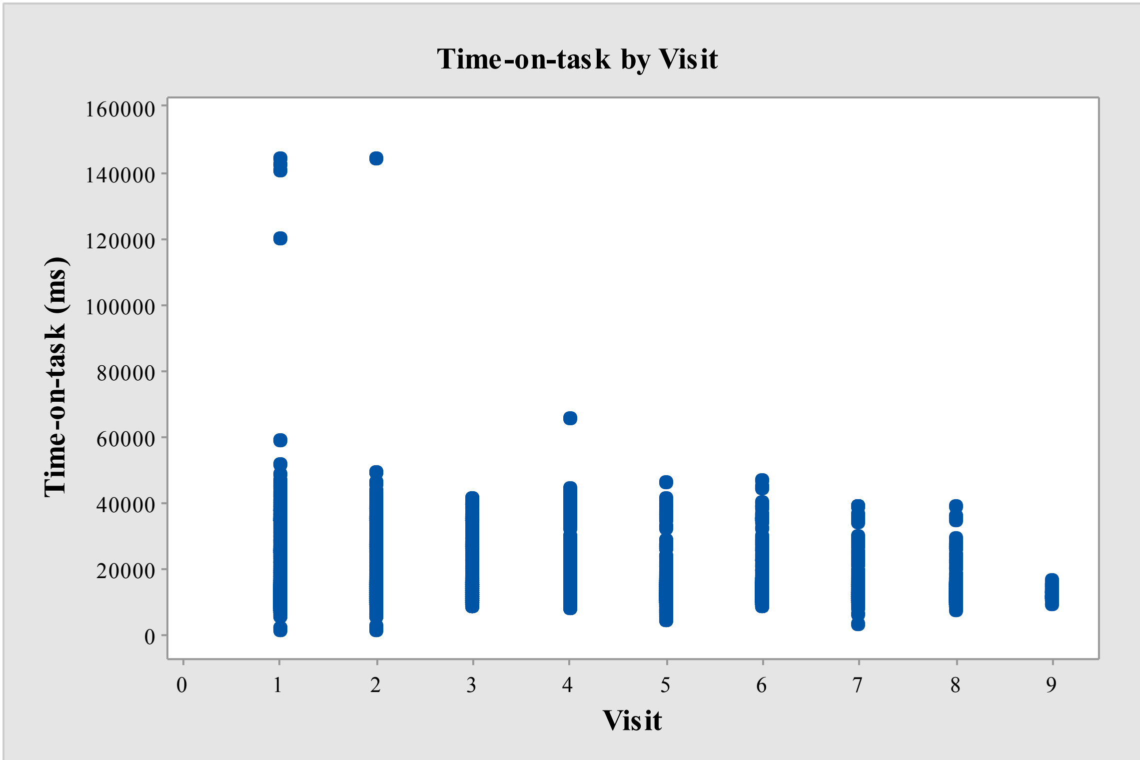


Figure 4.5. Scatter plot of inter-visit time-on-task data points for all subjects

Outliers were discovered for Visits 1, 2 and 4. According to the dataset, some subjects required over 140,000 milliseconds, or 140 seconds, to interact with the iris device. This time seemed unlikely because the subjects would have had to present for over two minutes. For exploration purposes, the outlier population was removed and the remaining time-on-task data points were again graphed on a box plot according to visit. Figure 4.6 shows the trends of this plot.

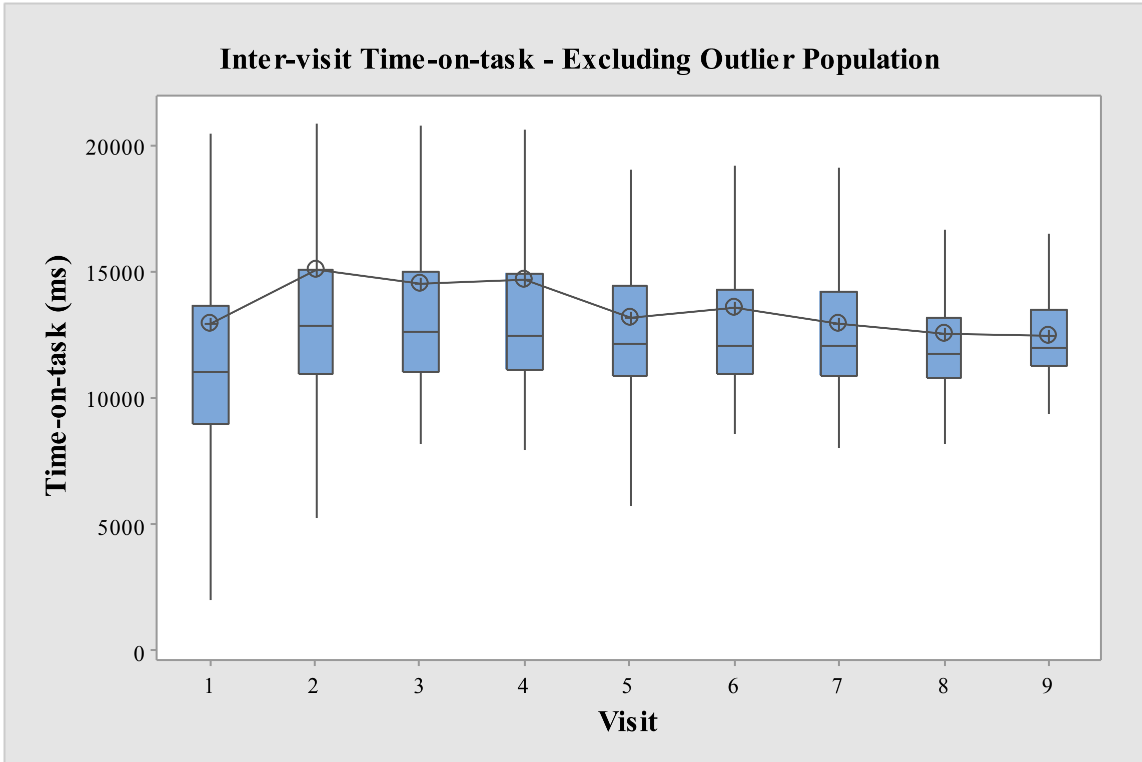


Figure 4.6. Box plot of inter-visit time-on-task distributions excluding outlier population

With the outlier population excluded, the means for Visits 1, 2 and 4 decreased slightly. Upon completion of the outlier examination, the analysis also considered the extended time span between Visits 1 and 2 caused by the device failure. The average time for a subject between Visits 1 and 2 was 239 days. Additionally, as most subjects were unaware of the device replacement, the increase in time-on-task further suggested that the extended time span between Visits 1 and 2 was the cause of the difference.

Further examination of Figure 4.6 showed consistent decreases in time-on-task following Visit 4 and continuing through Visit 9. A Kruskal-Wallis test confirmed that a significant decrease in time-on-task occurred from Visit 4 to Visit 5, with consistent decreases occurring after Visit 5 (N = 2240, H = 17.46, df = 1, $p < .001$). This result indicated that habituation trends were distinguishable when using the time-on-task metric and began after Visit 4.

Upon discovering that habituation effects may have been leading to improvements in time-on-task between visits, an examination of the changes in the time-on-task metric within a visit, or intra-visit habituation, was completed. This portion of the exploration sought to determine if time-on-task changed during a visit. As mentioned in Chapter 3, the methodology used for data collection required subjects to present their irises until 20 successful captures were made. A successful capture was considered any attempt that resulted in the capture of both eyes. If a subject failed to be captured during his or her visit, he or she was allowed five additional attempts to be successful, causing the number of presentations for any given subject to be between 20 and 25. A brief examination of the mean time-on-tasks within a visit was performed for each of the nine visits. Figure 4.7 shows the changes in time-on-task throughout the attempts for Visit 1.

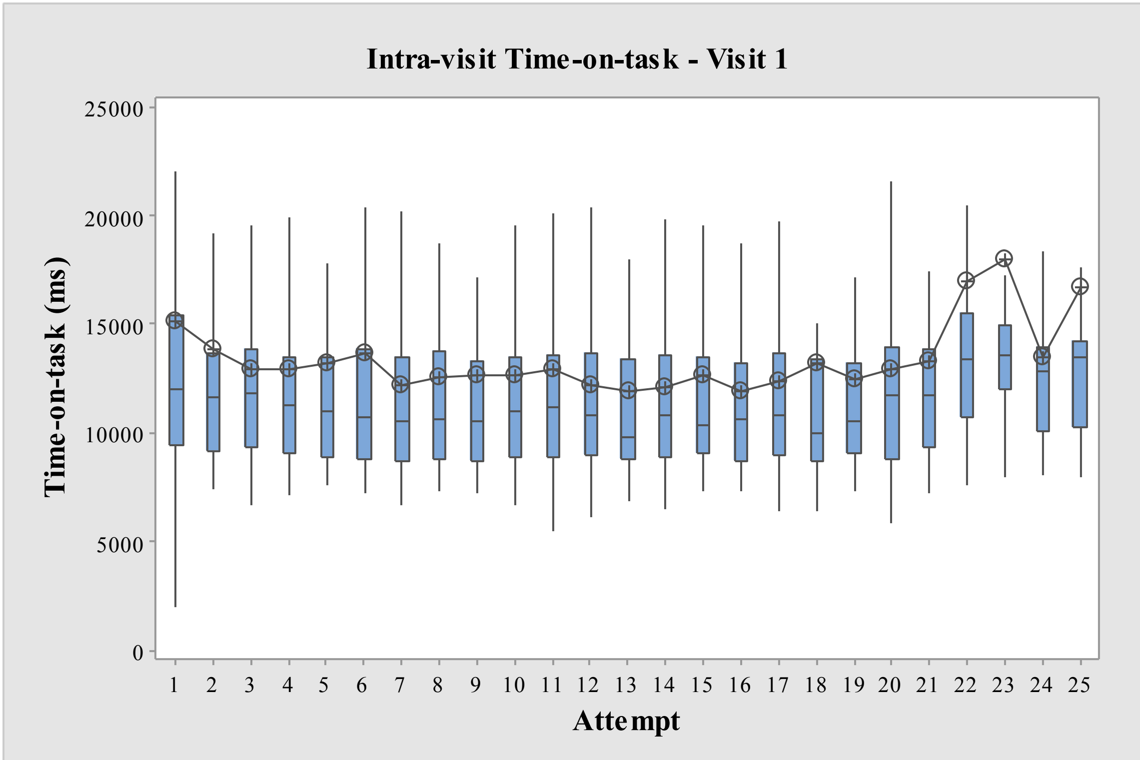


Figure 4.7. Box plot of intra-visit time-on-task distributions for Visit 1

Figure 4.6 indicates improvements immediately after the first attempt. These improvements continued through the fourth attempt before increasing. All changes following the fifth attempt were inconsistent and did not provide enough data to indicate any habituation trends. However, it was noted that the mean time-on-task spiked sporadically after the twentieth attempt by drastically increasing and decreasing. The cause of this spike was unknown at the time of analysis.

The intra-visit habituation exploration continued with the examination of Visit 2. Figure 4.8 reports the time-on-task changes for Visit 2.

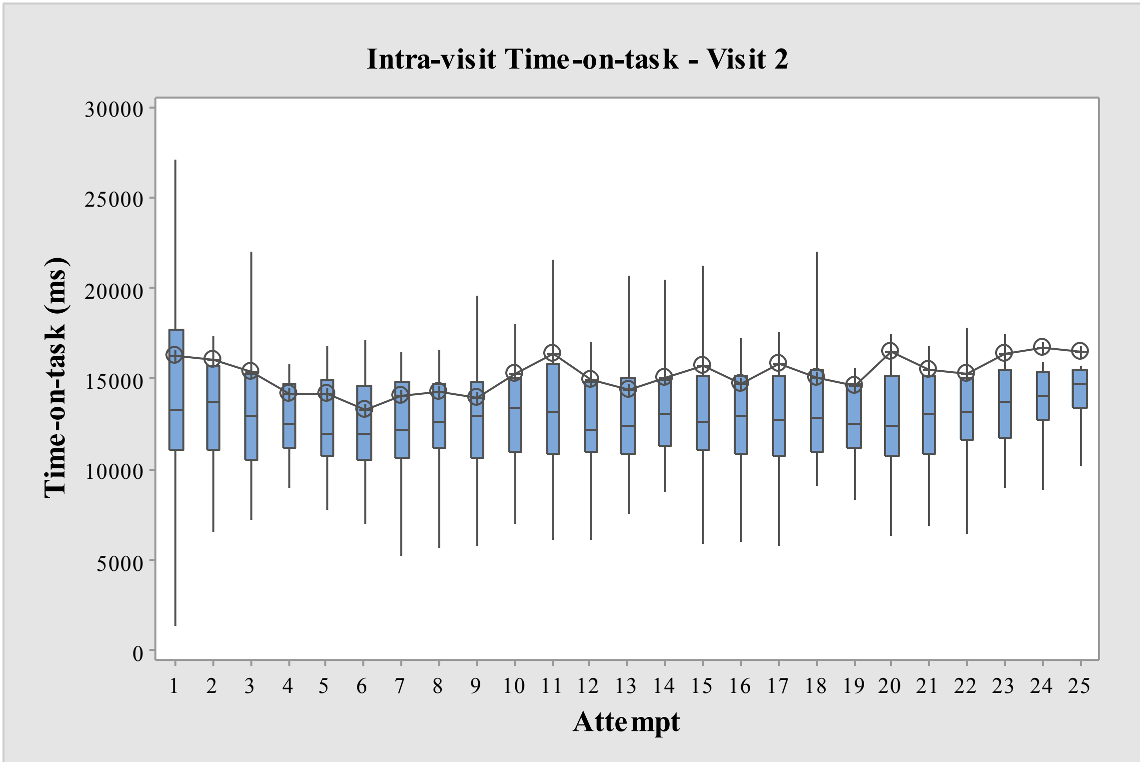


Figure 4.8. Box plot of intra-visit time-on-task distributions for Visit 2

Similarly to Visit 1, improvements in time-on-task were noticed at the beginning of the visit for the first few attempts. Other than the improvements noted in the first attempts, no consistent decreases in time-on-task were noticed. *Figure 4.9* presents the timing data for Visit 3.

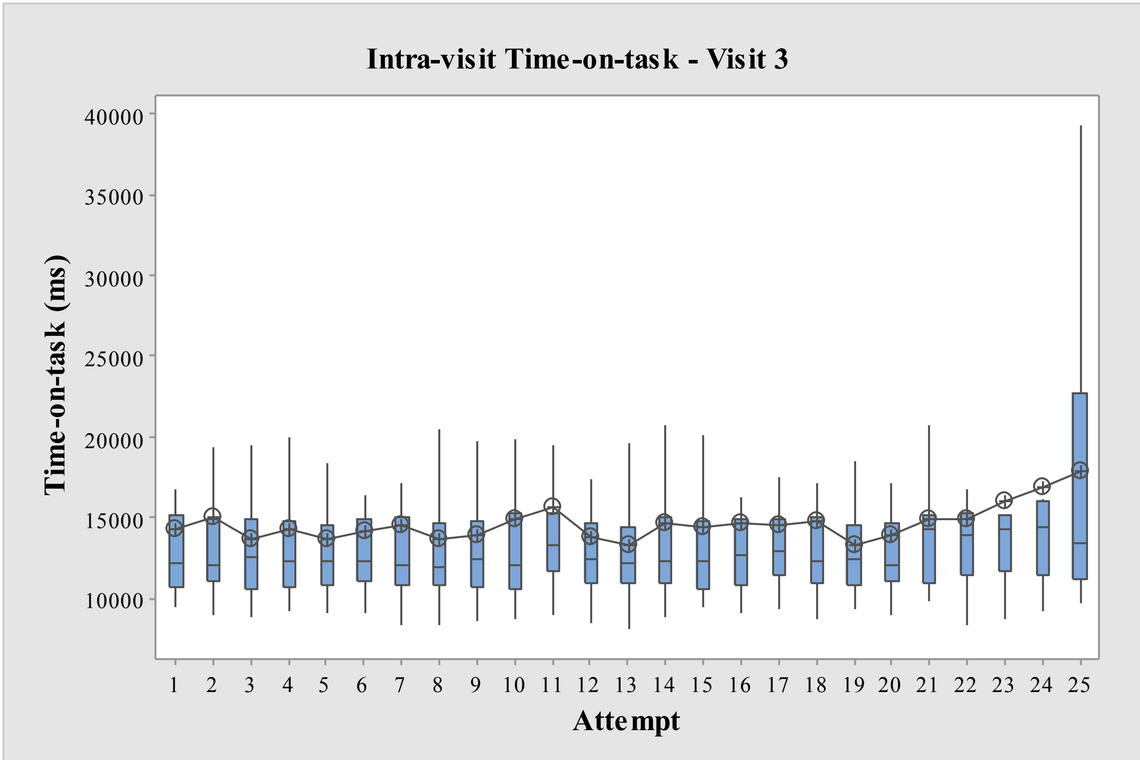


Figure 4.9. Box plot of intra-visit time-on-task distributions for Visit 3

Unlike Visits 1 and 2, consistent improvements were not observed at the beginning of Visit 3. Additionally, a spike at the end of the visit, specifically following the twentieth attempt and similar to that noticed in Visit 1, existed for this visit. Figure 4.9 suggests that the subjects were aware that the visit was close to completion and their presentations became more complacent, leading to more time being required. Figure 4.10 shows the time-on-task trends for Visit 4.

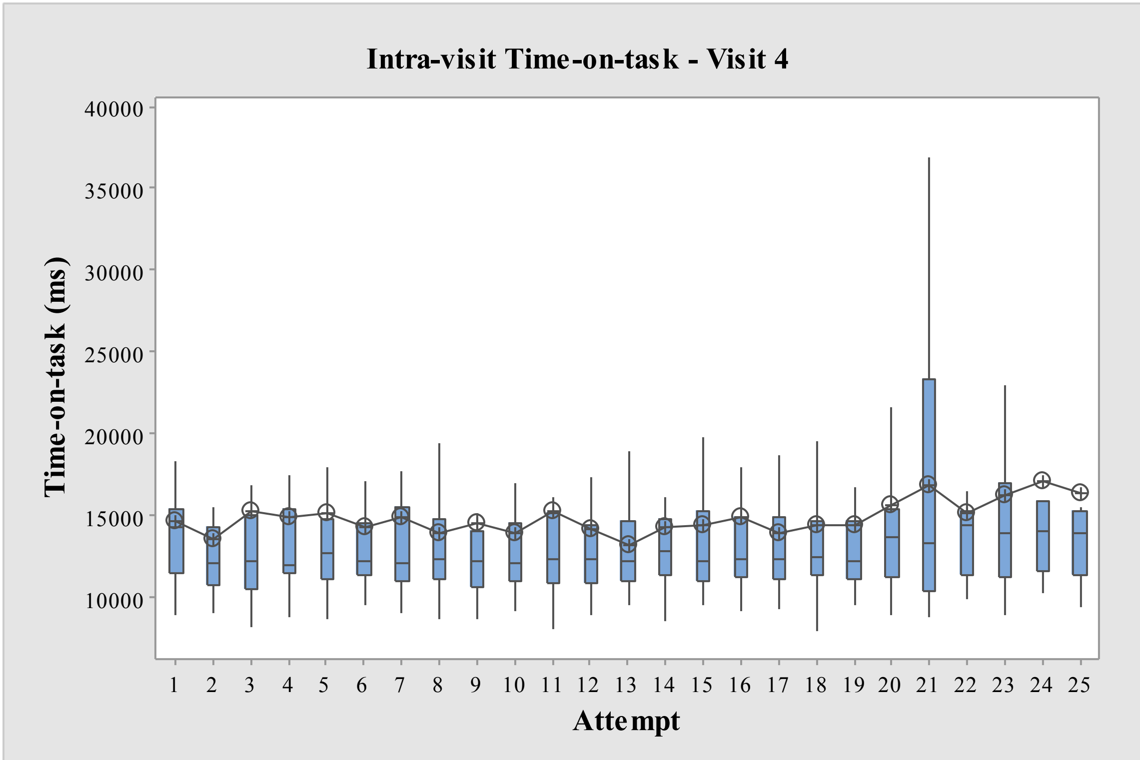


Figure 4.10. Box plot of intra-visit time-on-task distributions for Visit 4

Figure 4.10 indicates no consistent improvements. The time-on-task distributions throughout the Visit 4 attempts were slightly higher than those throughout Visit 3, but these data did not provide any indication of habituation trends within Visit 4. Figure 4.11 reports the time-on-task behavior for Visit 5.

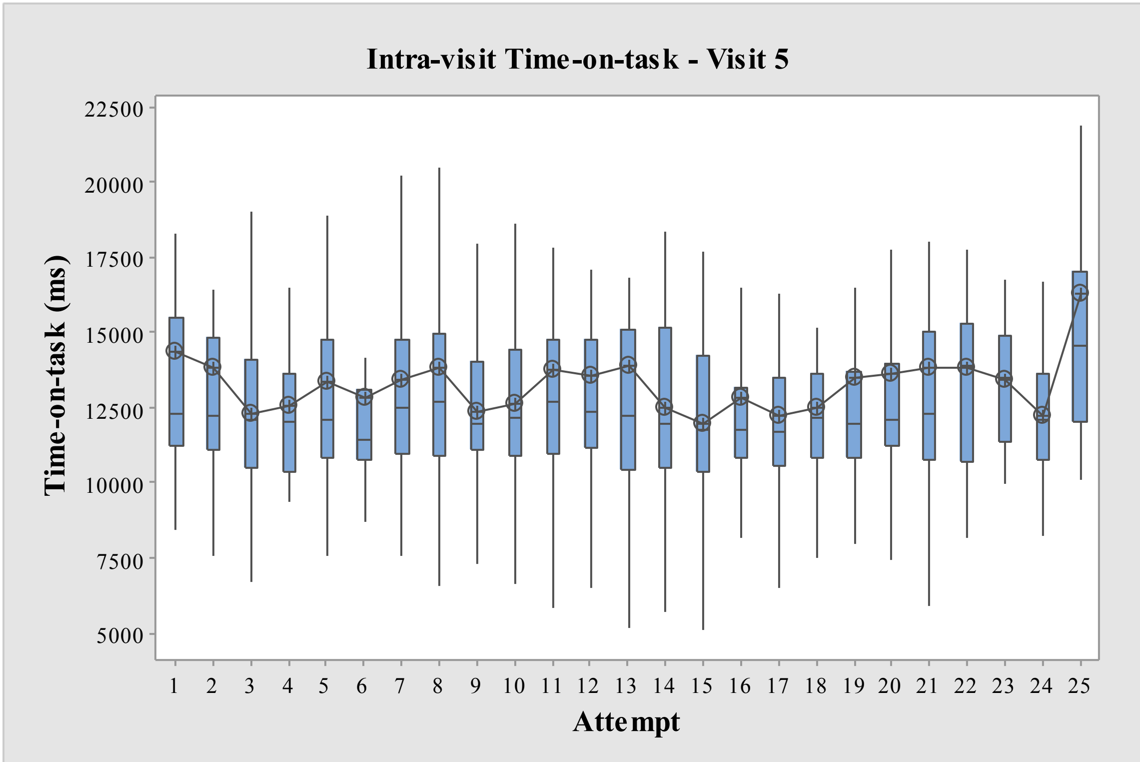


Figure 4.11. Box plot of intra-visit time-on-task distributions for Visit 5

Like Visits 1 and 2, a decrease in time-on-task was observed at the beginning of Visit 5 and also near the thirteenth and twenty-second attempts. However, no considerable progressive improvements or decreases were noticed. Additionally, similar spikes to those noted during the other visits were observed after the twentieth attempt. These spikes suggested that subjects were becoming complacent by the end of the visit. Figure 4.12 plots the results for Visit 6.

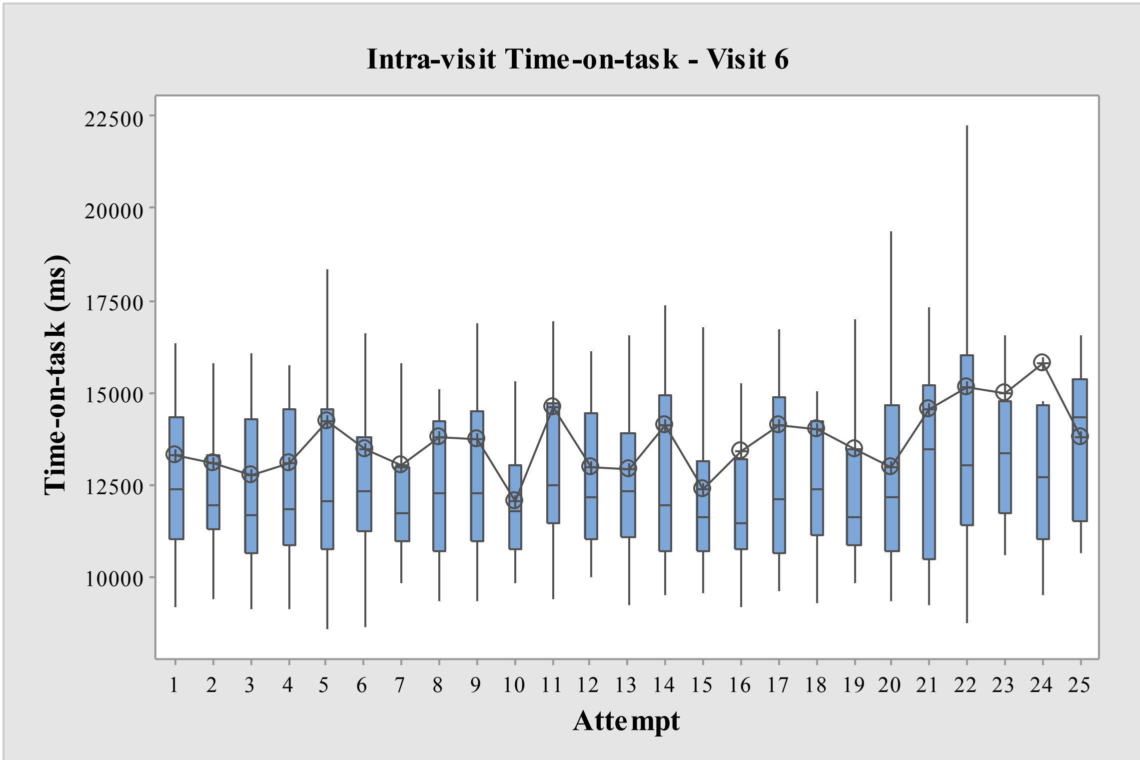


Figure 4.12. Box plot of intra-visit time-on-task distributions for Visit 6

Figure 4.12 indicates minor improvements at the beginning of Visit 6, but there were no obvious consistent improvements or increases. The mean increased by the end of the visit, matching the hypothesized complacent behavior during previous visits. This result indicated that beneficial habituation trends did not exist within this visit. Figure 4.13 reports the trends for Visit 7.

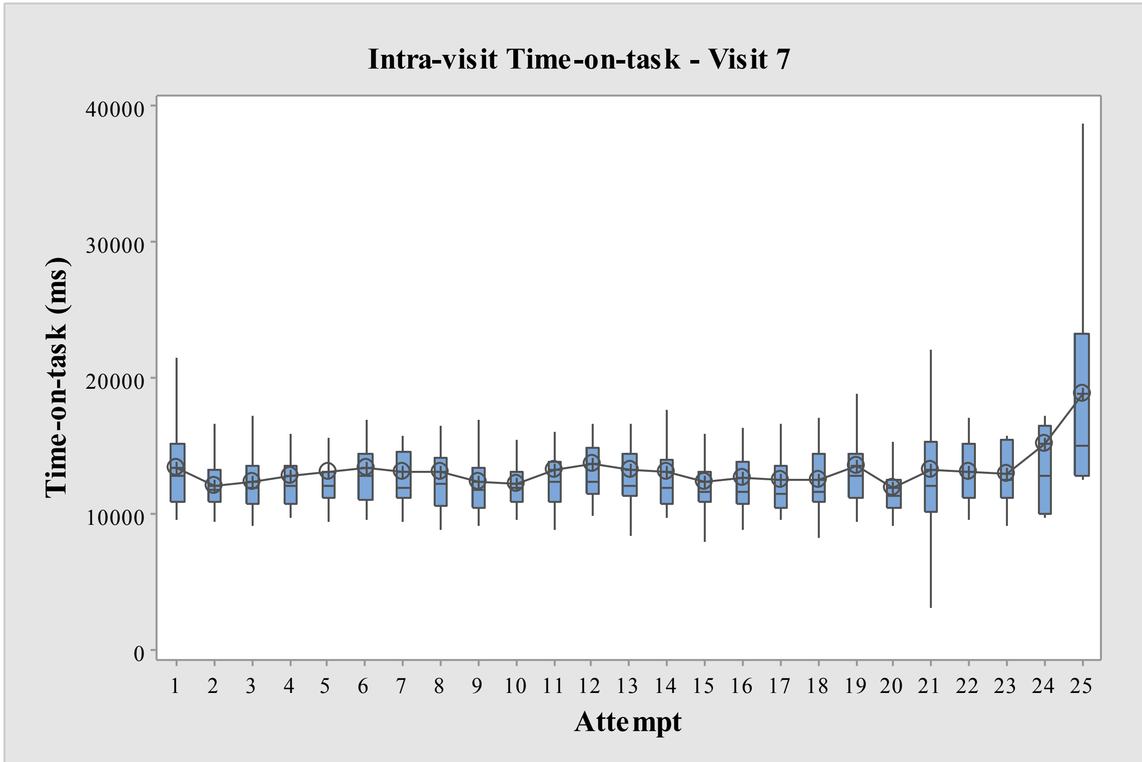


Figure 4.13. Box plot of intra-visit time-on-task distributions for Visit 7

Figure 4.13 indicates no consistent improvements. Downward trends were noticed after the seventh and twelfth attempts, but no indication of habituation was present. Like other visits, the mean time-on-task increased drastically after the twentieth attempt. Figure 4.14 graphs the Visit 8 time-on-tasks.

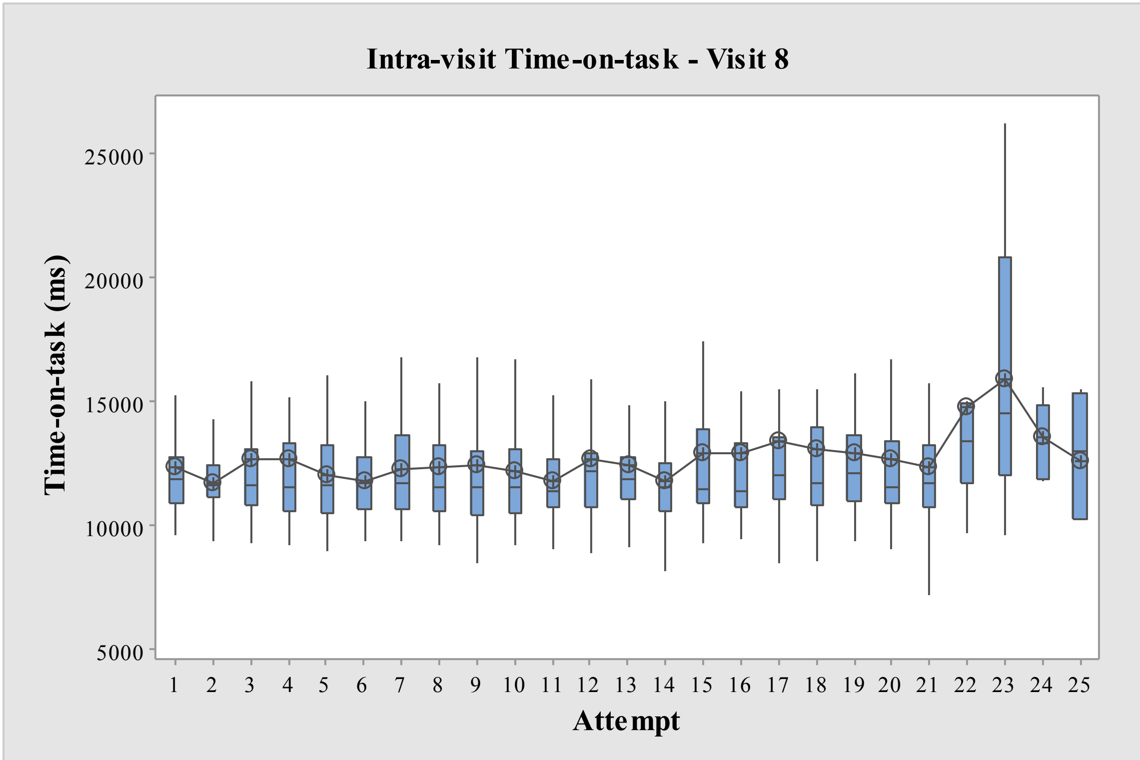


Figure 4.14. Box plot of intra-visit time-on-task distributions for Visit 8

As with previous visits, no distinguishable, consistent increases or decreases were observed during Visit 8. The changes in time-on-task generally remained flat until the twentieth attempt, with sporadic changes attributed to complacency. Figure 4.15, the last intra-visit plot, shows the mean time-on-tasks for Visit 9.

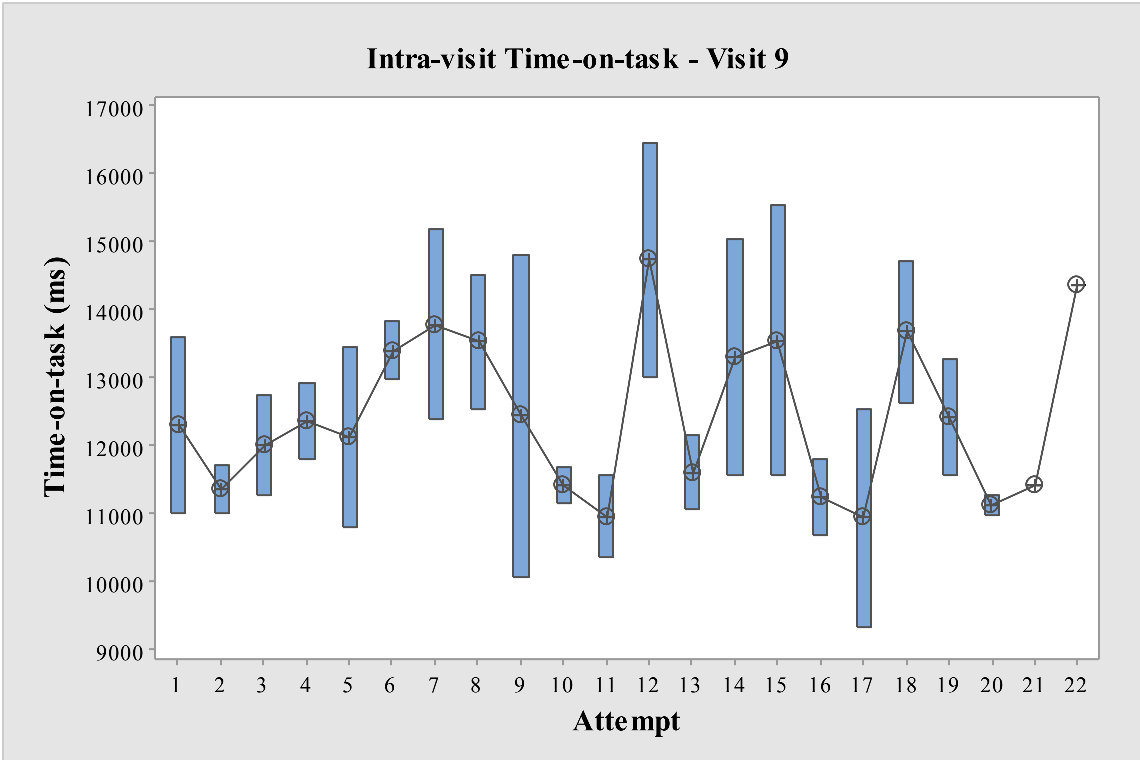


Figure 4.15. Box plot of intra-visit time-on-task distributions for Visit 9

Like most previous visits, no consistent progressive improvements were noticed during Visit 9. However, the progressive changes in mean time-on-task were sporadic, with drastic increases and decreases. It should be noted that only two subjects participated in the ninth visit because this visit consisted only of retakes due to the unexpected deletions of data during Visit 8. These data did not suggest that habituation effects were present within Visit 9.

This time-on-task exploration included a final examination. The trends observed throughout a visit did not include habituation trends. To determine changes in time-on-task as each subject first encountered the device at each visit, the study examined the time-on-task distributions for each visit by including only the first attempt for each visit in a final inter-visit plot. *Figure 4.16* shows the resulting trends.

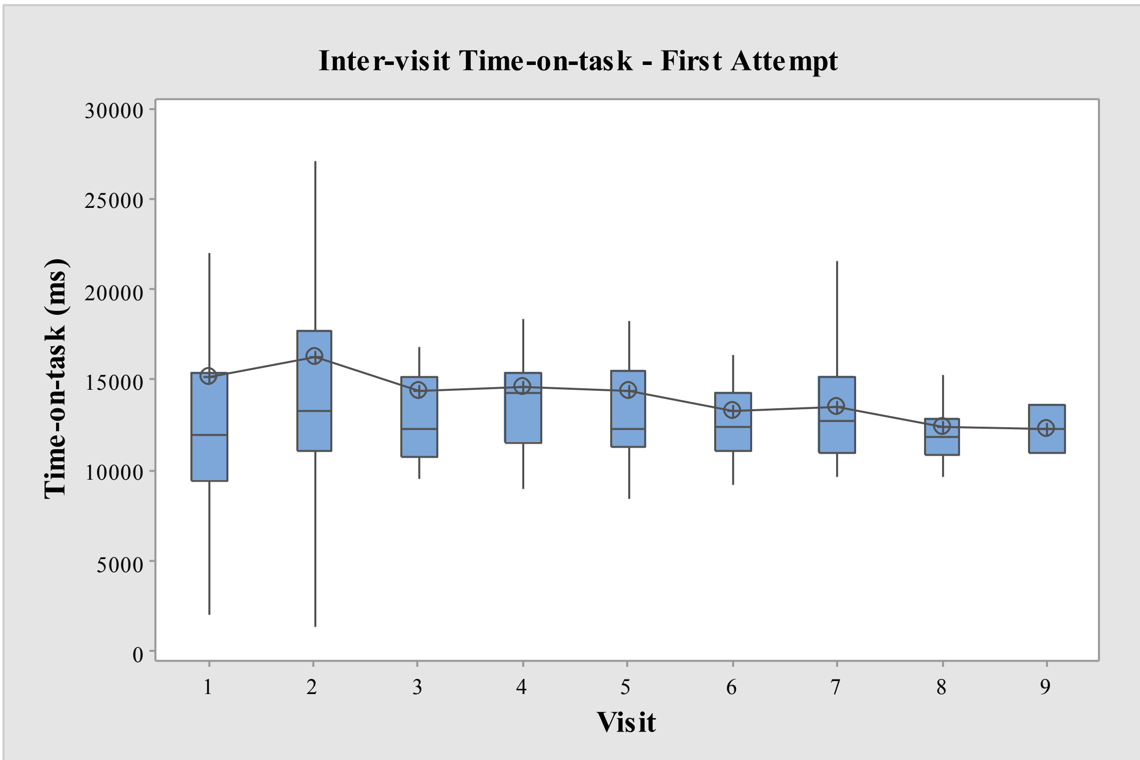


Figure 4.16. Box plot of inter-visit time-on-task distributions for only the first attempt of each visit

The above plot shows a consistent decrease in time-on-task after Visit 2 as visits progressed to Visit 9. A Kruskal-Wallis test did not confirm this decrease as to be significant (N = 145, H = 1.56, df = 1, p = .212). However, the consistent decreases in time-on-task suggested that subjects recalled how to interact with the iris camera, resulting in lower capture times at each visit's first attempt. An additional Kruskal-Wallis test resulted in statistical significance between Visits 2 and 8 (N = 114, H = 4.75, df = 1, p = .029).

The intra-visit plots showed no consistent increases or decreases, indicating that subjects did not experience habituation effects within a visit. However, the inter-visit plots did result in consistent improvements. This time-on-task exploration concluded that noticeable habituation trends occurred within the inter-visit time-on-task metric.

4.2.2 Image Quality Analysis

Image quality was examined to supplement the time-on-task analysis. The examination of image quality aimed to further characterize habituation in the context of the same data collection exercise used to examine time-on-task. Additionally, image data from a previous 2010 data collection exercise that used a similar device and application were included in this exploration to determine if habituation trends continued over separate data collection exercises. The images from both studies were processed using an image quality algorithm, Aware IrisCheck. This image quality algorithm assigned a quality score to each image between 0 and 1, with 0 representing the lowest quality and 1 the highest quality.

Due to improper naming conventions when the images were captured, the attempt numbers were not recorded. Because these attempt numbers were not properly organized, only inter-visit image quality was examined.

All image quality data were uploaded into the BSPA Labs database prior to analysis. To make the results reported in this thesis repeatable, a data run ID used by the BSPA database suite was assigned to the data exported for the following exploration and analysis. This data run ID was 1120. Table 4.10 reports an overview of these data.

Table 4.10. *Overview of image quality sample*

	Visit	# of Subjects	# of Images	Time Span from Previous Visit (days)			Image Quality		
				Min	Mean	Max	Min	Mean	Max
DHS 2010	1	261	2280	-	-	-	0.00	0.68	0.92
	2	238	7341	0	9	41	0.00	0.67	0.92
DHS 2012	1	77	2877	731	849	1045	0.00	0.58	0.86
	2	68	1916	3	232	289	0.00	0.59	0.91
	3	65	2589	3	12	22	0.00	0.59	0.91
	4	57	2308	4	12	26	0.00	0.57	0.89
	5	40	1643	4	9	30	0.00	0.58	0.89
	6	36	1482	5	9	29	0.00	0.60	0.90
	7	36	1519	4	7	21	0.00	0.61	0.87
	8	33	1371	1	8	20	0.11	0.60	0.89

A similar subject drop-off to that noted during the time-on-task analysis was noted for the 2012 image quality analysis. However because many images were purged due to the Aoptix memory reaching its maximum limit during Visits 1-3, the above samples are not representative of the full sample processed during the 2012 study. These values do represent the images that were collected and properly stored. This deletion issue was the cause of the drastic decrease in images during Visit 2 and the fact that no images were analyzed for Visit 9. The image quality scores for each visit during both data collection studies are presented as box plots in Figure 4.17.

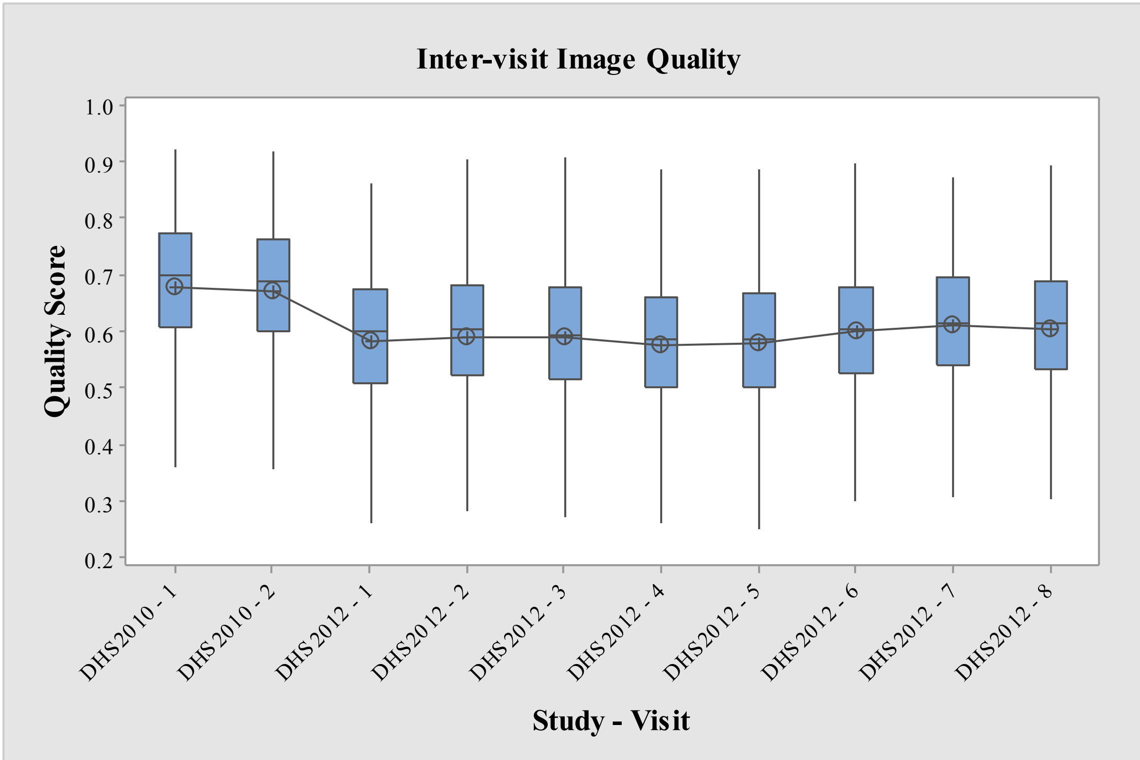


Figure 4.17. Box plot of inter-visit image quality distributions for each visit of the 2010 and 2012 data collection exercises

Figure 4.17 indicates a consistent improvement in image quality, starting with Visit 4 and extending through Visit 7 of the 2012 study. This improvement matched the improvements noted in the time-on-task analysis, further supporting the hypothesis time-on-task is an indicator of habituation.

Figure 4.17 shows a decrease in image quality between the 2010 and 2012 data collection studies. A further examination of the subject pools was completed to determine the cause of this decrease. Table 4.10 shows that the subject pools did not match between 2010 and 2012. Only 20 subjects from the 2010 collection participated in the 2012 exercise. Thus, all subjects other than those 20 subjects were temporarily excluded from the 2010 subject pool. Upon completion of the exclusion, the mean image quality scores were again graphed on a box plot. *Figure 4.18* shows the results of this exclusion.

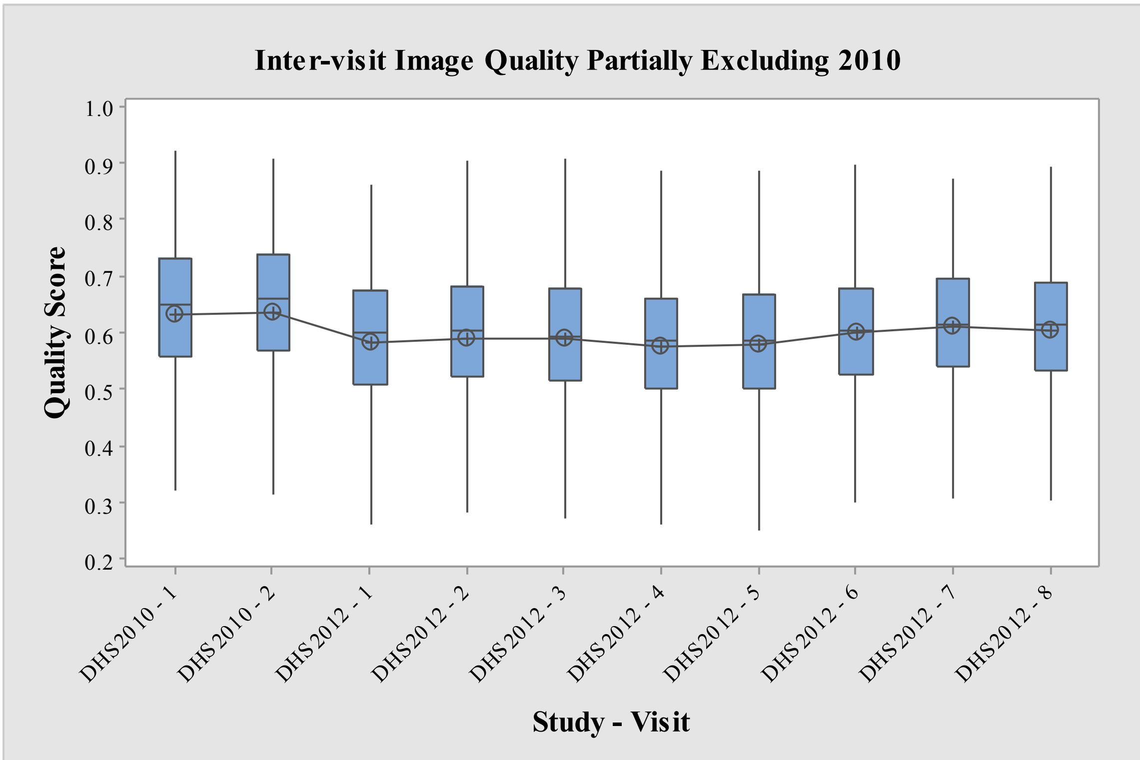


Figure 4.18. Box plot of inter-visit image quality distributions when partially excluding images from the 2010 data collection

After partially removing the 2010 subjects that did not participate in 2012, the mean image quality for the 2010 study dropped slightly. However, the mean quality for the 2010 data collection was still higher than that for the rest of the visits.

With only partial exclusion of the 2010 exercise, the trends for the entire sample showed consistent improvements following Visit 4 of the 2012 collection. The above boxplot suggests that habituation trends began occurring after Visit 4, and a Kruskal-Wallis test confirmed these improvements (N = 3790, H = 24.12, df = 1, $p < .001$).

Although the image quality trends were positive after Visit 4, a significant difference was noted between Visits 4 and 6. Therefore, the interpretation of mean image quality still suggested the occurrence of habituation trends.

4.2.3 Matching Performance Analysis

The results of the survey analysis suggested that image quality was highly correlated to matching performance. The inter-visit image quality trend plots showed consistent increases in image quality near the final visits, suggesting habituation effects. Therefore, the matching performance metric was examined to determine if matching performance could also show similar trends. Using the same dataset reported in Table 4.10, the analysis processed each visit, or dataset, against itself using Neurotechonology's Megamatcher. Each visit's set of images was exported from the ICBR database individually to maintain separation between visits. The data runs created to export the images of each visit are reported in Table 4.11.

Upon completion of the matching runs performed at each visit, the resulting match scores, specifically the genuine match scores, were recorded. Both genuine and imposter scores were also processed to determine the false reject rates (FRR) at false accept rates (FAR) of .01, 0.1 and 1.0. Table 4.11 shows the results of this processing and the data pulls used to export the images for analysis.

Table 4.11. *Overview of matching performance results*

	Visit	Data Run ID	# of Genuine Matches	Genuine Scores Min	Genuine Scores Mean	Genuine Scores Max	FRR FAR 1.0	FRR FAR 0.1	FRR FAR 0.01
DHS 2010	1	1168	6834	5	825	1532	0.03	0.03	0.03
	2	1169	60649	0	518	1532	0.27	0.29	0.32
DHS 2012	1	1170	31053	0	575	1532	1.89	1.98	2.11
	2	1171	19978	0	555	1532	4.52	4.61	4.64
	3	1172	28282	0	563	1532	0.61	0.69	0.79
	4	1173	25731	0	549	1532	0.52	0.60	0.71
	5	1174	17973	0	556	1532	0.38	0.38	0.41
	6	1175	16535	0	573	1532	0.46	0.48	0.49
	7	1176	17031	0	578	1532	0.18	0.19	0.22
	8	1177	15044	96	575	1532	0.00	0.00	0.00

The drop-off in subjects noticed during the 2012 collection reflects the number of genuine matches shown in the above table. Additionally, the number of genuine matches for the 2010 collection reflects the capture process for each visit because the first visit collected only eight images from each subject, while the second visit collected 30. Figure 4.19 shows the data presented in the table as box plots.

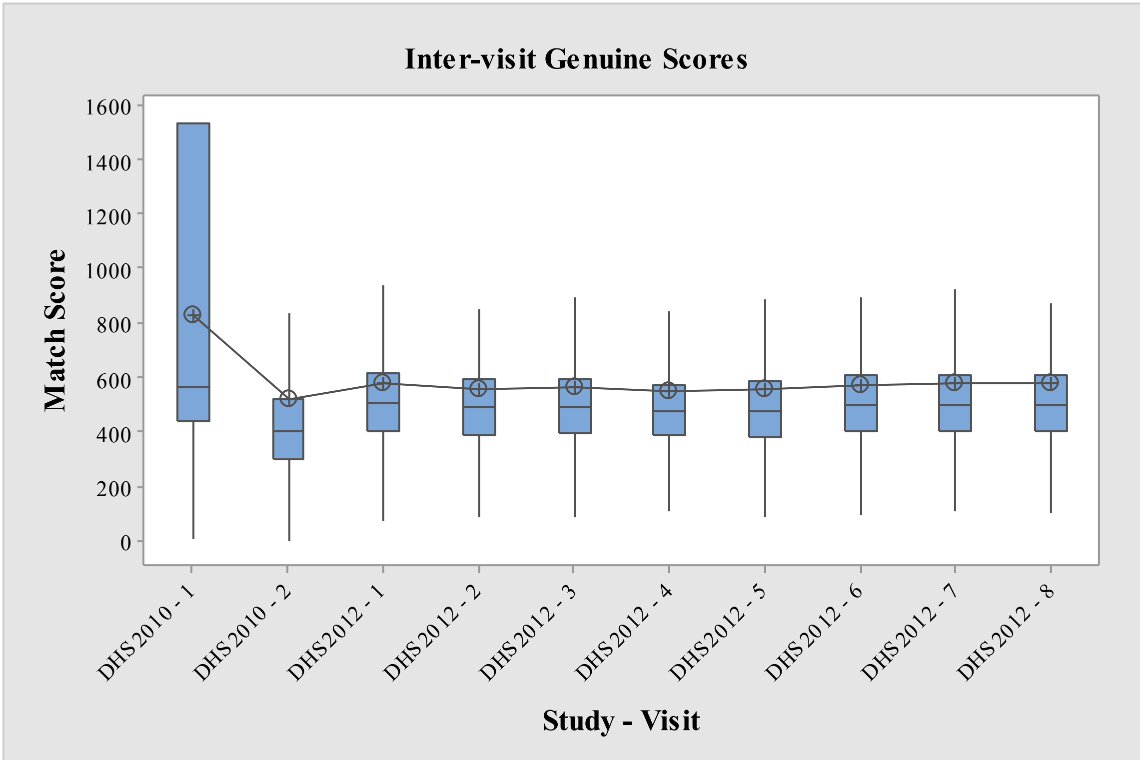


Figure 4.19. Box plot of inter-visit genuine score distributions for each visit in the 2010 and 2012 data collection exercises

Figure 4.19 shows a spike in genuine scores during the first visit of the 2010 study, with a mean score of 825. After an examination of the genuine scores, images matched to themselves received the maximum match score of 1532. Because the 2010 Visit 1 collected only eight images, compared to the 15 or more images collected at the rest of the visits, the images matched to themselves increased the mean genuine scores. Therefore, any match scores resulting from images matching to themselves were temporarily removed. Figure 4.20 shows the results of this exclusion.

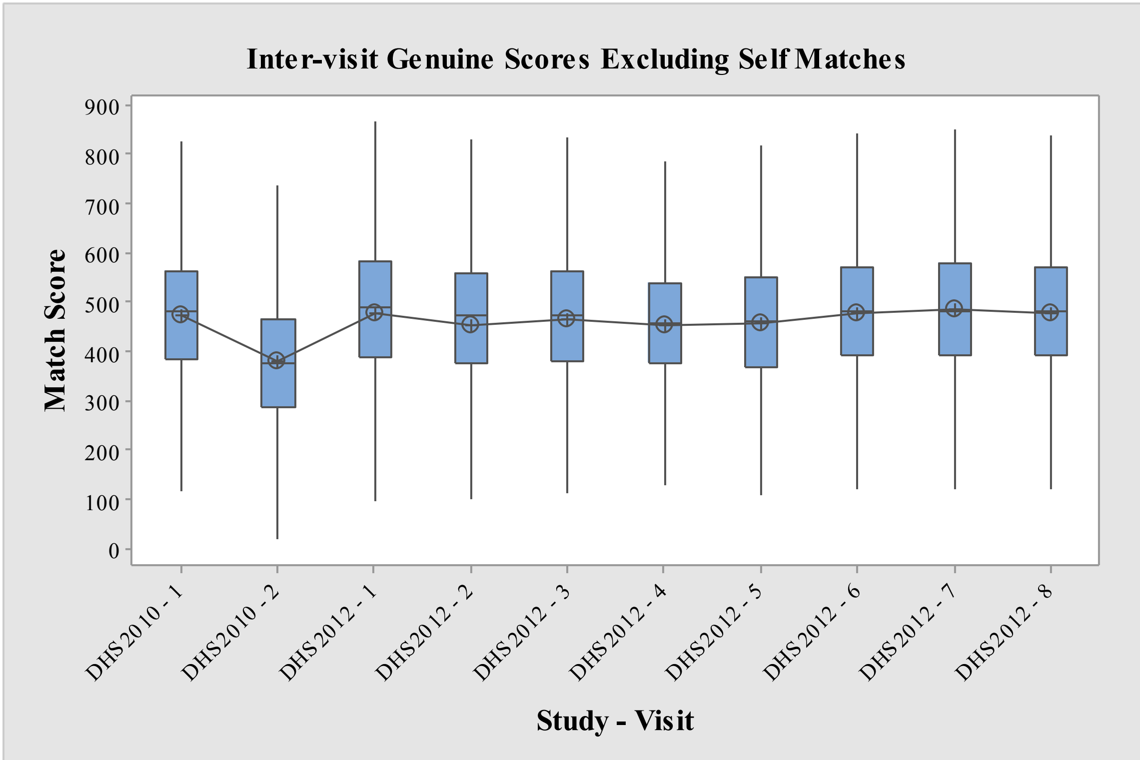


Figure 4.20. Box plot of inter-visit genuine score distributions excluding self-matches

Figure 4.20 indicates that the exclusion of self-matches lowered the mean genuine score of each visit by approximately 200. The trend across visits remained generally flat. However, a considerable decrease occurred during the second visit of the 2010 study. The analysis theorized that the drop in match scores was caused by the higher number of subjects, which in turn led to a higher amount of images to which each image was matched.

Consistent increases were noted following Visit 4 of the 2012 exercise and continued through Visit 8 when self-matches were excluded. A similar type of improvement was noticed in both the time-on-task and image quality analyses, and a

Kruskal-Wallis test validated that a significant increase in genuine scores occurred following Visit 4 and continued until Visit 7 ($N = 39753$, $H = 4.17$, $df = 1$, $p = .041$).

Additionally, referencing Table 4.11, the processing of both genuine and imposter scores resulted in a continuous drop in false reject rates at all levels of false accept rate. The false reject rates began to drop steadily after Visit 3 until they achieved perfect match rates, or a 0.0% false reject rate, for Visit 8. Because the match score relied on other images in a dataset and because the datasets were not balanced, conclusions were not made based on the match rates. However, with the statistically significant increase in genuine scores and the drops in false reject rates, the results of the matching performance analysis provided enough evidence to suggest habituation trends were occurring and identifiable after Visit 4.

4.2.4 Conclusions of the Data Collection Analyses

The results of these data collection analyses indicated that time-on-task began to improve significantly after Visit 4 during the 2012 data collection exercise. Subjects who continued to return for visits showed continual decreases in the amount of time required to be captured by the iris camera. This result suggested that as subjects returned for visits, they were able to recall the capture process from previous visits, resulting in distinguishable improvements following Visit 4 of the 2012 study and indicating the occurrence of inter-visit habituation. Time-on-task was also examined for trends within individual visit, but no intra-visit habituation trends were identified.

Consistent improvements in image quality and matching performance also occurred after Visit 4. Subjects who repeatedly interacted with the device were able to submit higher-quality images and achieve a higher level of matching performance. Images from a 2010 iris data collection, using a similar capture device, were included in the image quality and matching performance analyses. The trends in image quality and matching performance showed no distinguishable habituation effects between the 2010 and 2012 data collection exercises.

The similarities noted among all three variables suggested that habituation effects were existent and both consistent and identifiable after Visit 4 of the 2012 study.

4.3 Summary of Chapter 4

Two types of analyses were performed in this mixed-methods thesis to characterize habituation in an iris recognition system. First, a habituation survey was given to experts in the biometric community that served three roles: to show that the overall perspective on habituation was not consistent throughout the biometric community, to provide verification that the methodology used for the quantitative analysis was sound and to determine if experts thought time-on-task could be used as an indicator of habitation. Second, using a proposed data collection methodology, trends in time-on-task, image quality and matching performance were characterized to determine if the effects of habituation were identifiable in an iris recognition system.

CHAPTER 5. CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

This study examined the concept of habituation using a thorough literature review, a survey to discover perspectives on habituation among biometric experts and an analysis of iris data collected in 2010 and 2012. A limited set of literature has attempted to define habituation in a biometric context (M1.5, 2003; Kukula et al., 2007; & Theofanos et al., 2006), and research that attempts to define it in an iris recognition system is even more limited. A more expansive review of habituation was possible in a social science context (Rankin et al., 2009), but this literature does not elaborate on habituation in the context of a biometric system.

Based on the literature review, it was hypothesized that habituation was not well understood in the biometric community. Therefore, a survey was given to 13 biometric experts in an attempt to illustrate this inconsistency and provide a framework for methodology that would best determine the existence of habituation. The hypothesis that time-on-task was an efficient indicator of habituation was made with this framework, and an analysis of the 2012 data collection exercise was completed to determine if habituation trends were present. Additionally, an analysis of both matching performance and image quality was performed on the 2010 and 2012 data collection exercises to further explore habituation in an iris recognition system.

This final chapter concludes the thesis by comparing the responses received for the habituation survey and the results of the quantitative analysis. Immediately following this comparison are final conclusions, recommendations for further investigation and future work.

5.1 Comparison of Habituation Survey to Data Collection Analyses

This section of the analysis compared the results found in the habituation survey, described in Section 4.1, to the results found in the quantitative analysis of Section 4.2. The comparison began with Question 2 because Question 1 simply asked biometric experts to provide their age and years of biometric experience. Additionally, Questions 10 and 12 were not compared to the quantitative results because these questions were asked for exploration purposes only and were not considered in the design of either the 2010 or 2012 data collection exercises.

5.1.1 Question 2

Question 2 asked, “How would you define habituation in general?”

Analysis of this question suggested that biometric habituation is defined as the process of a user becoming familiar with a biometric system by accustoming to the process of being captured. This familiarity is achieved by repeatedly using the system and can result in improvements to the collection process.

The quantitative analyses of the 2010 and 2012 iris data collection exercises showed improvements in time-on-task, image quality and matching performance. As subjects continued to return for repeated visits and became more familiar with the iris capture process, the mean trends in time-on-task, image quality and matching performance began to show distinguishable improvements, specifically after Visit 4 of the 2012 collection exercise. Following Visit 4, subjects began to show a decrease in the time needed to interact with the system, in addition to providing higher quality images, which also attributed to improved matching performance.

5.1.2 Question 3

Question 3 of this survey asked, “Do you think habituation has an effect on biometric systems? If yes, why do you think it is important? If no, why not?”

Analysis of Question 3 showed that biometric experts universally understood that user habituation to a biometric system can affect overall system performance. In this context, overall system performance can refer to the throughput of the system and its ability to perform an effective biometric match, and performance improvements are achieved through the user changing his or her behavior to the system’s benefit or detriment.

The trends observed in the quantitative analysis showed that habituation has beneficial effects on overall system performance. All three variables, time-on-task, image quality and matching performance, resulted in significant improvements near the end of the 2012 data collection, implying that overall system performance had begun to improve. Additionally, the habituation trends indirectly suggested that habituation does affect human behavior because subjects needed to change their presentation techniques to achieve the resulting improvements.

Analysis of the intra-visit time-on-task trends showed a spike in the time needed to interact with the device near the end of most visits. This study hypothesized that subjects nearing the end of a visit became more complacent in their presentations, resulting in increased time needed to interact with the device and further suggesting that habituation influences user behavior.

5.1.3 Question 4

Question 4 asked, “Do you believe that acclimation and habituation are synonyms? If not, what is the difference?”

Analysis of the habituation survey showed that respondents did not universally understand the difference between acclimation and habituation. The disparity noted in the responses suggested that half of the biometric community did not believe that acclimation was an occurrence in biometric implementations. Based on the respondents who did believe acclimation was a separate process from habituation, this study concluded that acclimation occurs early in a complete interaction with a biometric system. The user considerably modifies his or her presentation techniques during this phase, leading to inconsistent trends in time-on-task, image quality and matching performance. The user transitions from the acclimation phase into habituation when the desirable presentation techniques are discovered. During habituation, the user begins to show consistent improvements in the measured variables.

The trends in time-on-task, image quality and matching performance observed during the quantitative analysis showed that consistent improvements were generally unidentifiable until Visit 4 of the 2012 data collection exercise. Prior to Visit 4, the trends in the measured variables were inconsistent and did not imply habituation. The trends in time-on-task, image quality and matching performance suggested that acclimation did occur among subjects at any visit prior to Visit 4 of the 2012 study. The consistent improvements noted after Visit 4 indicated that this visit represented the transition from acclimation to habituation. Figure 5.1 shows this transition in a boxplot of inter-visit time-on-task trends.

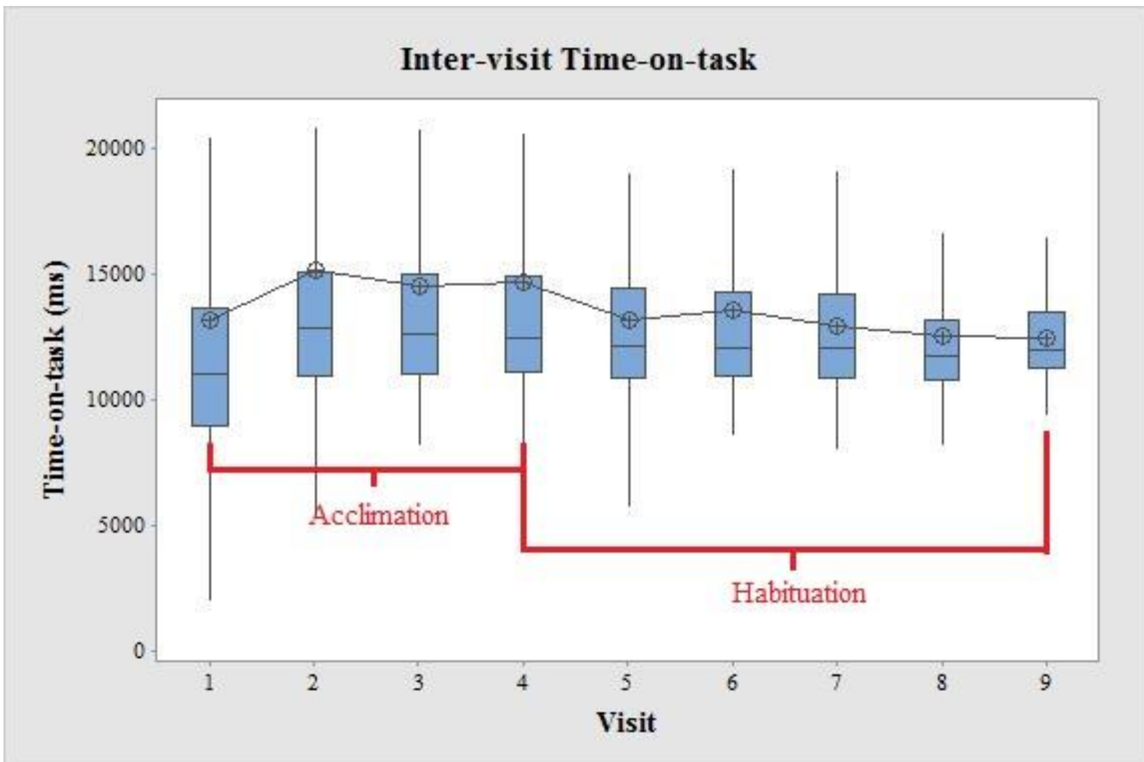


Figure 5.1. Box plot of inter-visit time-on-task trends depicting the transition from acclimation to habituation

5.1.4 Question 5

Question 5 asked, “Do you believe the influence of a system administrator, through feedback or initial instructions, affect habituation? If so, in what ways does such influence affect habituation? If not, why not?”

Analysis of Question 5 showed that all the respondents believed instruction and feedback from the system administrator can affect habituation. The responses to the follow-up questions showed varying opinions of how instruction and feedback can cause habituation effects, with half of the respondents attributing effects to a change in user behavior and the other half stating that it effects overall system performance. As both methods result in a change in overall system performance, this study concluded that initial instructions and feedback from the system administrator can influence how a user presents to a biometric device, and these changes in user behavior will influence the system’s performance.

System administrator instruction and feedback was not included in the quantitative analysis of the 2010 and 2012 data collection exercises. Initially, the test protocol for the 2012 collection provided system administrators with a script that informed the subjects of the iris camera’s capture process. The protocol also stated that system administrators should not provide real-time feedback unless directly requested by the subject, in which case the system administrator should provide the appropriate feedback and record the feedback given. Miscommunication between test designers and system administrators resulted in both deviations from the initial instruction and inconsistently recorded feedback. Based on a post-collection briefing with all the data collectors who participated in the 2012 collection, which allowed them to report on the instruction and feedback given, this thesis concluded that system administrators did provide feedback that may have had an impact on the progression of habituation in subjects.

5.1.5 Question 6

Question 6 asked, “Do you believe there are different phases of habituation that can occur over time? How would you differentiate the different phases?”

Analysis of Question 6 showed that the respondents agreed habituation occurs in phases. Similarly to Question 4, the responses differentiating between phases of habituation coincided with the differentiation of acclimation and habituation. Other than this similarity, the responses did not share any distinguishable commonalities.

The results of the quantitative analysis showed the occurrence of only two distinguishable phases, acclimation and habituation. The improvements in time-on-task, image quality and matching performance showed consistent improvements only following Visit 4. The trends in the measured variables did not indicate further phases of habituation other than acclimation and habituation itself.

5.1.6 Question 7

Question 7 asked, “Do you believe habituation affects the quality of a given sample? If so, in what ways do you think habituation affects the quality? If not, why not?”

Analysis of this question showed overall agreement that habituation can affect the quality of a collected image. The respondents collectively stated that higher levels of habituation can lead to higher levels of image quality. Conversely, if a user becomes too habituated, presentations to the biometric device can become complacent, resulting in lower image qualities.

Analysis of the data collections resulted in consistent, significant increases in image quality following Visit 4 of the 2012 study. Using Aware IrisCheck, the processing of images showed inconsistent decreases in image quality, reflecting the acclimation phase prior to Visit 4. Additionally, the image quality trends matched the time-on-task habituation trends. These results validated the survey’s responses and showed that habituation has an effect on the quality of collected images within a biometric system. Figure 5.2 is a boxplot that shows the inter-visit image quality trends for the 2010 and 2012 data collection exercises.

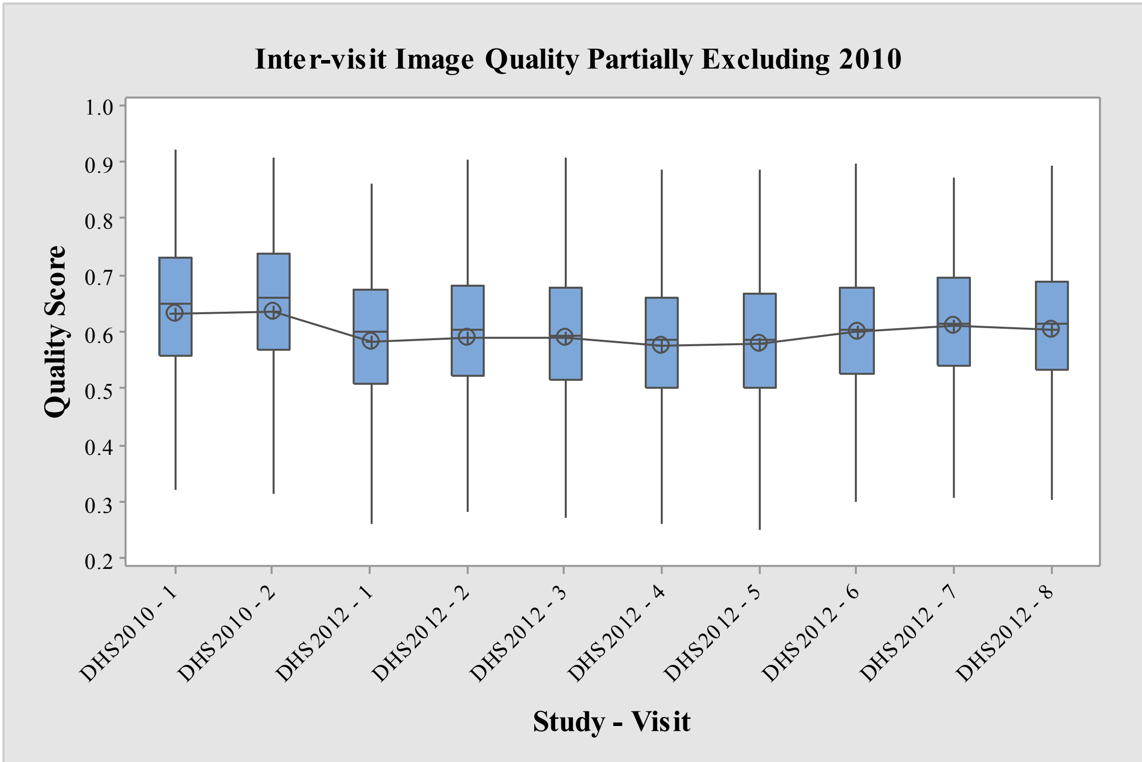


Figure 5.2. Box plot of inter-visit image quality trends depicting consistent improvements following Visit 4

5.1.7 Question 8

Question 8 asked, “Do you believe habituation directly affects the performance of a given sample? If so, in what ways do you think habituation affects the performance? If not, why not?”

Similarly to Question 7, analysis of Question 8 showed that respondents agreed habituation could affect the matching performance of a given dataset. The results suggested that matching performance is correlated to the quality of images within that dataset. Referencing Question 7, the respondents stated that user behavior can affect image quality. Using data from both Questions 7 and 8, this study interpreted responses stating that habituation can affect user behavior, which will influence the quality of the image collected. The resulting quality determines the ability of the image to match others.

This study utilized Neurotechnology's Megamatcher to match the images of each visit individually. As with time-on-task and image quality, the resulting genuine scores showed consistent, significant improvements following Visit 4 of the 2012 data collection exercise. Unlike time-on-task and image quality, the genuine scores of the visits prior to Visit 4 remained flat, rather than inconsistent. The trends in the false reject rates, however, showed improvement starting with Visit 3. This result suggested that habituation effects from matching performance were identifiable prior to the identification of effects from time-on-task and image quality. The consistent improvements in matching performance, similar to those for image quality, showed that habituation can influence matching performance. Figure 5.3 shows a boxplot of the improvements noted in the genuine score trends starting after Visit 4.

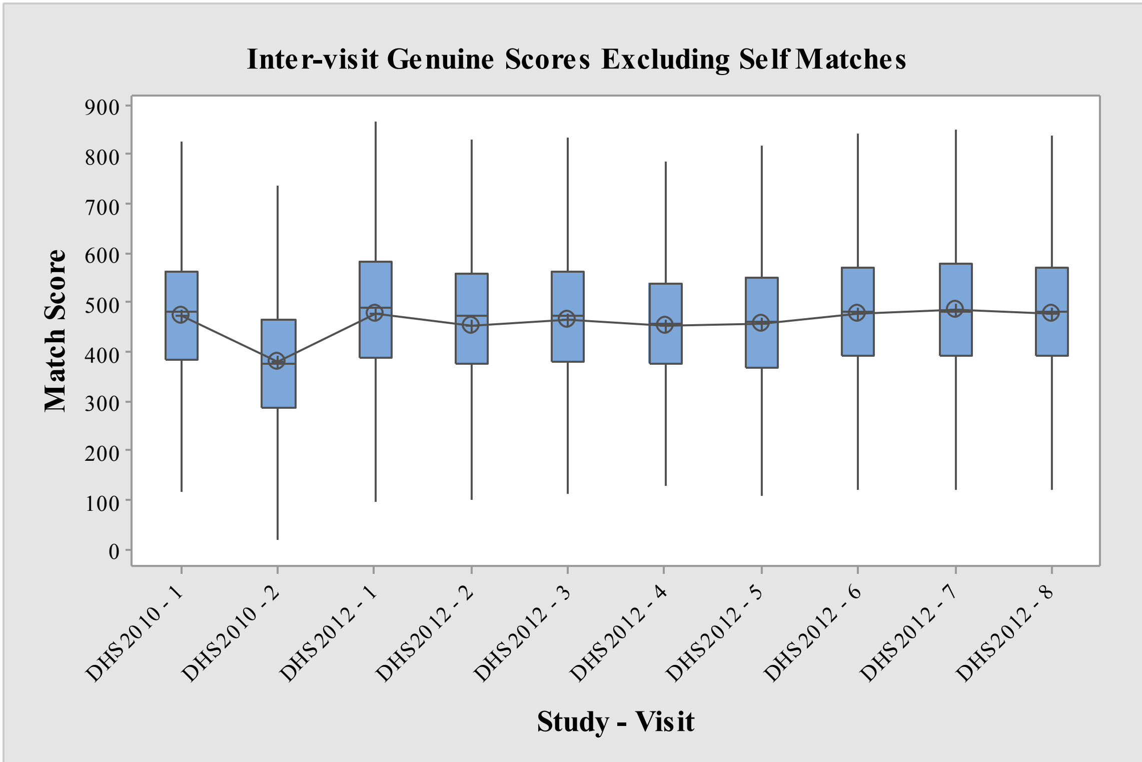


Figure 5.3. Box plot of inter-visit genuine score trends depicting consistent improvements following Visit 4

5.1.8 Question 9

The ninth question in the habituation survey examined the concept of dishabituation. The question read, "Dishabituation is defined as 'the restoration of a habituated response by extraneous stimulation'. In biometric terms, your habituated presentation changes when a different stimulus is used. Do you believe that "dishabituation" occurs? If so, what do you believe causes dishabituation?"

Examination of Question 9 showed that biometric experts had inconsistent concepts of dishabituation. To date, the term dishabituation has been published only in the social science literature (Rankin et al., 2009). Unsurprisingly, two experts did not believe dishabituation exists, and five did not provide responses. The six respondents that did believe dishabituation exists provided enough evidence, through common themes, to suggest that dishabituation occurs within a biometric system as a result of a change in the system's environment or a lack of repeated device use.

Upon completion of the 2010 and 2012 data collection exercises, six scenarios had taken place that could have allowed dishabituation to occur. First, the capture process for the 2010 study changed, leading to possible decreases in image quality and matching performance. The first visit of the 2010 collection both enrolled and verified subjects, while the second visit solely verified subjects based on the enrollment of the first visit. Analysis of the image quality and matching performance trends for 2010 showed a decrease in both variables from Visit 1 to Visit 2, suggesting that dishabituation had occurred. Figure 5.4 depicts the hypothesized dishabituation trends.

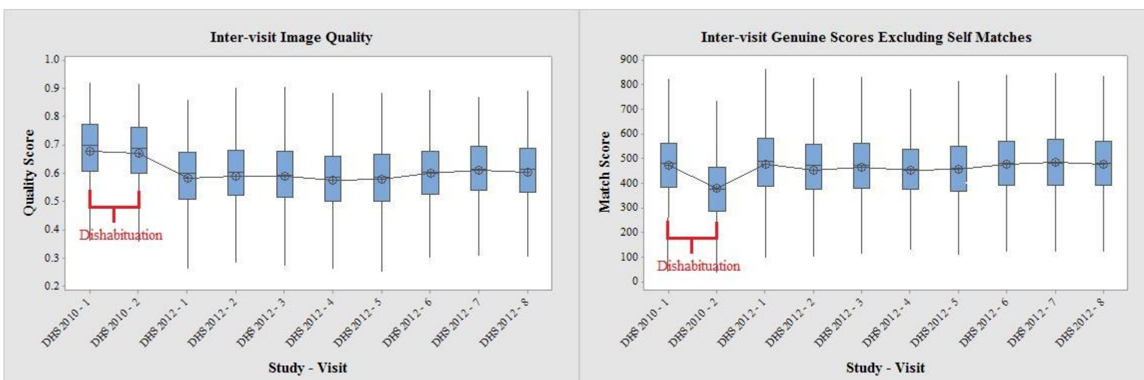


Figure 5.4. Boxplots depicting dishabituation according to image quality and matching performance for the 2010 data collection exercise

The 2010 and 2012 data collections were also separated by a time span of two years, and a newer version of the Aoptix iris camera was used for the 2012 collection. This change not only led to an extended period of non-use but also caused a change in the system environment. Analysis of the image quality and matching performance trends showed a considerable decrease in image quality from Visit 2 of the 2010 collection to Visit 1 of the 2012 collection, suggesting dishabituation had occurred. Figure 5.5 shows this trend in image quality.

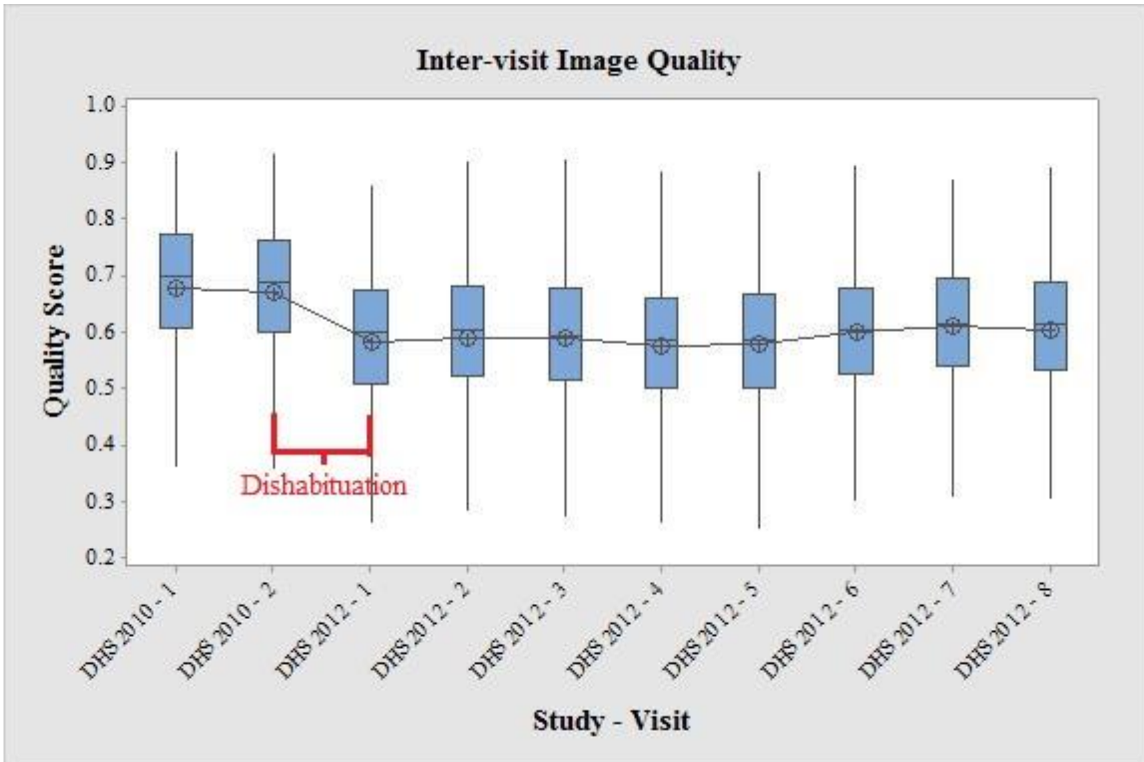


Figure 5.5. Boxplot depicting dishabituation in image quality between the 2010 and 2012 data collection exercises

Finally, a device failure occurred during the 2012 data collection exercise between Visits 1 and 2. To allow for the study's continuation, Aoptix sent a new, identical device to the one that had failed. During the time between the two visits, test designers also noticed that the capture area had been delineated by a 2 x 2-foot box during Visit 1, when the manufacturers had called for a 1 x 0.66-meter box. The test designers changed the capture area to measure 1 x 0.66 meters before Visit 2 started. The replacement of devices and the change in capture area caused a change in the system environment because the Visit 2 device was not the same as that used in Visit 1. Additionally, because the replacement of the faulty device was not instant, the time span between Visits 1 and 2 of the 2012 study extended the average time span between visits to 239 days. Analysis of the time-on-task, image quality and matching performance trends showed considerable increases in time-on-task and decreases in genuine scores, suggesting dishabituation had occurred. Figure 5.6 shows the dishabituation trends in time-on-task and matching performance between Visits 1 and 2 of the 2012 data collection exercise.

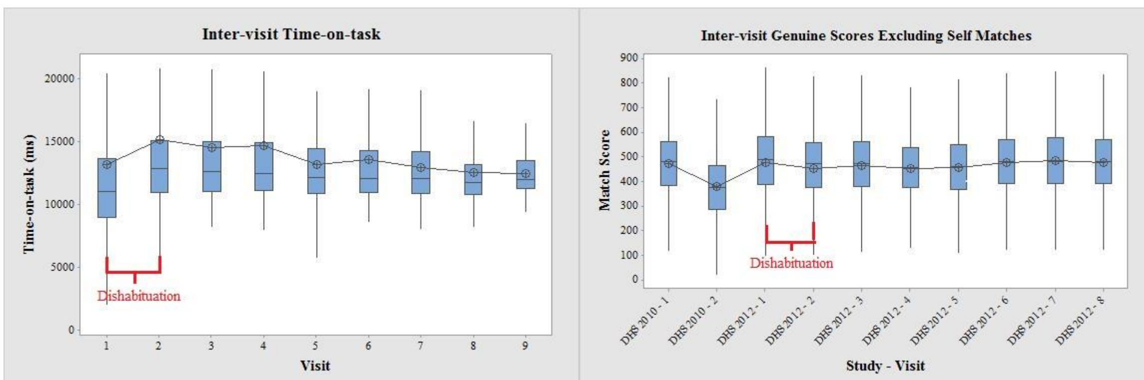


Figure 5.6. Boxplots depicting dishabituation in time-on-task and matching performance for the 2012 data collection exercise

Based on the trends observed during the occurrence of changes in the system environment and extended time spans, this study concluded that dishabituation does occur and can be caused by changes in the capture environment and extended time spans between use.

5.1.9 Question 11

The analysis used the responses to Question 11 to verify that the methodology designed for the quantitative analysis was a viable method with which to characterize habituation in an iris recognition system by allowing biometric experts to rank influential factors. Question 11 posed the following statement: “Many factors exist that may affect or habituation in a subject. Some of these factors may be more influential on habituation than others. Please rate the following factor's influence on habituation (0 being "not influential at all" and 10 being "very influential)”. Ultimately, based on the responses received, the study concluded that habituation was a result of repeated use and training/feedback given to subjects. The more a subject used a device and the more compact the uses were, the more likely habituation was to occur. Additionally, higher-quality feedback given to subjects would result in higher and accelerated habituation effects. Table 5.1 presents the responses received for Question 11 by listing the total responses, mean rank score of each factor and standard deviation of each factor. Following Table 5.1 is a summary of how each factor was designed for the data collection exercise that formed the basis of the quantitative analysis.

Table 5.1. *Factors in Responses to Question 11*

Factor	Total Responses	Mean Score	Standard Dev.
Number of interactions per visit	9	9.33	1.41
Number of attempts per visit	9	9.33	1.73

Training given to subject	9	9.22	1.79
Test administrator feedback	9	8.89	1.45
Number of visits device is used	9	8.78	1.99
Length of time between each visit	9	8.67	1.73
Complexity of device interaction	9	8.67	2.40
Subject IQ	9	7.00	3.81
Change of environment	8	6.75	2.60

The number of interactions and number of attempts per visit were designed for both data collection exercises through the multiple images each subject was required to submit. This method allowed for multiple uses of the device by each subject at all visits.

The training given to the subject and test administrator feedback was scripted for the 2012 data collection, but no conclusions were made from these components of the exercise because deviations from the training/feedback occurred. This scenario was verified by a post-collection briefing and is further discussed in Section 5.1.4.

The number of visits for which the device was used was designed into both data collection exercises by requiring the subjects to return for multiple visits. It was assumed and then verified that habituation was more identifiable in the 2012 data collection exercise because more visits were employed than in the 2010 exercise.

The length of time between each visit was inadvertently designed into the methodology with the inclusion of the 2010 data and the device failure that occurred during the 2012 study. In the original methodology for this thesis, only the 2012 data collection was to be used, and the time between visits was to remain fixed at one week.

However, with the inclusion of the 2010 data and the device failure, two extended time spans were introduced, and the results suggested that habituation was less likely to occur when long periods of time existed between visits, leading to dishabituation.

The complexity of the device interaction was initially intended for design into the 2012 exercise by changing the way the subject presented to the device from visit to visit. However, it was ultimately decided that the complexity of the device interaction should remain consistent throughout all visits in the 2012 data collection exercise. Therefore, this factor became irrelevant.

Subject IQ was also initially intended for design into the 2012 data collection. However, this factor was deemed impractical because each subject would be required to complete an IQ test. Therefore, the factor became irrelevant, but it is included as a recommendation for future work because Yehuda et al. (1979) states that higher IQ could result in accelerated habituation.

Change of environment was inadvertently designed into the methodology with the inclusion of the 2010 data and the device failure that occurred during the 2012 exercise. In the original methodology for this thesis, only the 2012 data collection was to be used. Two device changes were introduced with the inclusion of the 2010 data and the device failure, but these changes were ultimately concluded to be irrelevant because all of the devices were from the same manufacturer and used the same specifications. It was assumed that changes to devices obtained from different manufacturers would introduce an influence on the rate of habituation. Therefore, this factor is included as a recommendation for future work.

5.1.10 Table Map of All Analyses

The above comparison of the habituation survey to the quantitative analysis interpreted the trends noted in time-on-task, image quality and matching performance in the context of the responses received for the habituation survey. Table 5.2 provides a map of each individual analysis for reference.

Table 5.2. *Table map of all analyses performed*

Analysis of	Page Number
Question 1	62
Question 2	65
Question 3	70
Question4	74
Question 5	77
Question 6	81
Question 7	83
Question 8	86
Question 9	90
Question 10	93
Question 11	94
Question 12	97
Time-on-task Analysis	101
Image Quality Analysis	117

Matching Performance Analysis	121

5.2 Conclusions

The results of this research identified multiple phenomena.

After analyzing the responses received directly from biometric experts for the habituation survey, this study showed that the various aspects of biometric habituation are not yet understood or well defined. The number of contradicting responses to most questions provided evidence that the majority of biometric experts did not share the same definition of habituation. However, critical components of habituation were identified by finding common themes shared by multiple biometric experts. In terms of these common themes, the study defined habituation as “a level of familiarity with a biometric device implementation achieved by accustoming users to the capture process. To become accustomed to the capture process, the user must repeatedly interact with the device to modify presentation techniques until improvements in overall system performance are observed”.

The results of the quantitative research showed that as subjects repeatedly interacted with an iris camera during multiple attempts over multiple visits, the mean time from initial device contact to capture completion began to consistently decrease. The habituation trends noticed in time-on-task were significantly identifiable after the majority of subjects returned for four visits. Additionally, subjects were able to submit higher-quality images following four visits, which caused genuine match scores to increase. The improving trends in time-on-task, image quality and matching performance showed that the system performance consistently improved as subjects repeatedly used an iris camera, providing evidence that habituation trends can be identified using the time-on-task metric.

This thesis research defined habituation and observed habituation trends through the time-on-task metric. Most importantly, however, the research determined that habituation can be only generally defined in the field of biometrics. To be beneficial, the specific definition of habituation must include the biometric modality, the biometric device and its application. The identification of habituation may not be practical in short-term applications, such as small data collection exercises, because the device's application may change in a short time period. However, for a biometric system in which the application and device remain constant, such as fingerprint devices used to track international travel, the identification of habituation trends can be beneficial to throughput and sample quality.

5.3 Recommendations

A number of additional research questions and concepts were raised during this study and are recommended for future investigation.

1. This study did not analyze specific quality metrics other than overall quality score, such as blur or gaze angle. Further research could show that habituation can also cause changes in the behavior of the iris itself.
2. Only time-on-task, matching performance and image quality were analyzed to show habituation trends. Current research by the International Center for Biometric Research at Purdue University attempts to automatically capture the

physical behavior of a subject using Microsoft Kinect. Further studies could examine possible changes in physical behavior as a result of habituation.

3. This thesis analyzed only one modality for habituation. Future studies could examine other modalities, such as face or signature, for similar effects and determine whether habituation also exists in other modalities.
4. This study analyzed only one iris device for habituation. Future studies could examine other iris devices, such as fixed-field devices, to determine habituation effects over a variety of iris devices.
5. This thesis analyzed only one application of an iris device for habituation. Future studies could examine applications used for tasks other than collection to determine if habituation can be specifically defined.
6. The 2012 data collection captured timing data for only nine visits, but improvements in time-on-task were still being observed through Visit 9. It was hypothesized that habituation would result in eventual stability in the variables studied. Data collection exercises that exceed nine visits may be able to illustrate this theorized stability.
7. Similarly to the above recommendation, an eventual stability could illustrate full habituation. The subconscious ability to interact with a device mentioned in Kukula et al. (2007) could be a reference to this eventual stability. Because a continuous improvement was noticed through Visit 8 of the 2012 study, this stability was not observed. O’Connor (2013) uses stability as a means of further examining the biometric menagerie, and a similar methodology could be used to show that full habituation has been achieved.

8. This thesis used only time-on-task, matching performance and image quality to characterize habituation. It is possible that improvements in other variables could also show the existence of habituation. Future research into these improvements could advance the definition of habituation.
9. In Kukula et al. (2007), researchers split subjects into four groups. Each group uses the hand geometry device at a different frequency to determine if frequency of use affects habituation. Future research of habituation with iris recognition should consider the inclusion of groups using the device at different frequencies to understand why a subject habituates.
10. Question 10 of the habituation survey asked respondents to explain the practicality of classifying different habituation levels to improve feedback. This task was not possible for the data collection exercises used in this thesis. Therefore, further data collections specifically designed to examine the progression of habituation in unhabituated subjects could allow for the classification of habituation levels.
11. Yehuda et al. (1979) states that IQ levels could be a factor in the acceleration of an individual's habituation process. Future data collections should incorporate a subject's IQ to determine if higher IQ levels result in accelerated habituation.
12. This thesis concluded that biometric modality, device and implementation must be considered to specifically define habituation. Future studies could pinpoint common applications, such as building access, and begin to specifically define habituation for such applications.

5.4 Future Work for Practice

The results of this thesis can be applied in future work to enable targeted design improvements. This study concluded that the biometric community did not universally understand all aspects of habituation, and the results of this survey analysis could be used to further examine common applications, such as the biometric applications currently used for international travelers entering the United States, to create specific definitions and criteria for identifying habituation in long-term implementations. The study also concluded that habituation led to improvement trends in time-on-task, image quality and matching performance. Long-term biometrics applications could utilize the time-on-task metric not only as an indicator of habituation but also to determine the impact habituation has on throughput. In particular, with the identification of habituation in an operational environment, system integrators could mitigate risk by ensuring that implemented biometric devices achieve the highest level of throughput possible using extensive implementation design and proper system operator training.

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APPENDICES

Appendix A Consent Form for the 2010 Data Collection

Research Project Number

For IRB Office Use Only

RESEARCH PARTICIPANT CONSENT FORM
Iris Recognition Study
Stephen J. Elliott, PhD
Purdue University
Department of Industrial Technology

Purpose of Research

This research will be used to test the performance of an iris recognition system. Outcomes of this study will help in furthering the understanding of iris camera performance under different lighting conditions and how to improve an iris recognition system.

Specific Procedures

As a participant, you will be provided with a copy of this informed consent form to read and sign if you choose to participate. Demographic information will be collected and includes the following: height, age, gender, ethnicity, presence of contact lenses (specifically hard, patterned, and/or colored). You will be given a short briefing presentation followed by a practice session to learn how to use the iris camera.

Once the practice session is over, you will be asked to enter the capture area. You will then look at the iris camera. The camera will capture a picture of your iris, and you will then leave the capture area. You will repeat this three more times if the images were captured properly. If the camera cannot capture your iris, we will try two more times to capture. Once you have finished the first visit, you will be asked to schedule a second visit in about a week's time. At the second visit, you will be asked to step in a square on the floor. There are five squares. At each location, we will take pictures of your iris in different light levels, (low, medium and high). You will repeat this sequence in the four other positioning locations. At the third visit, you will be asked to step into a square on the floor for enrollment of your iris and then exit the capture area. You will be asked to complete five validation attempts exiting the capture area before each validation attempt.

Duration of Participation

This study consists of 3 visits, lasting approximately 50 minutes (one 10 minutes, the second 30 minutes, and the third 10 minutes).

Risks

This study poses minimal risk to you; no more than occurs in everyday activities. Iris images will be collected without identifying information; however all first visit iris images collected in this study will be included in a dataset that will be delivered to the National Institute of Standards (NIST). These images will be made public under the IREX II test. All the data will be maintained indefinitely for research by the Purdue University's Biometric Standards, Performance & Assurance (BSPA) Laboratory. Only authorized researchers from Purdue's BSPA laboratory AND AOptix involved in biometrics research will have access to the database. The data is does not contain any personally identifiable information, except for images of the iris. Again, the data delivered to AOptix and NIST will not contain any personally identifiable information, except for images of the iris; however there is risk that you could be identified.

The iris camera is an experimental device using a lighting source that is near Infra-Red. An investigational device is one that is not approved by the U.S. Food and Drug Administration (FDA). While design calculations have determined that the illumination is eye safe at the position each subject would take during the experiment, there may be some risk of injury. AOptix has determined that the experimental device has been considered Non-Significant Risk. The study will also include bright lights. The most discomfort you are expected to feel during or immediately after completion of a procedure is temporary eye discomfort that is similar to the experience of a consumer camera flash.

Benefits

There are no benefits to you as a participant. However, the administrator of fingerprint scanners may benefit from the result of this study as it will allow researchers to recommend the best force range to be used to improve quality performance.

______ Initials ______ Date

Research Project Number

Compensation
You will be paid a sum of $15 only if you complete visit 1 and 2 of the research study. You will be paid an additional $5 separately at the completion of visit 3. You will not be compensated for early withdrawal. All the collected information will be destroyed if you decide to withdraw from the study.

Injury or Illness
Purdue University will not provide medical treatment or financial compensation if you are injured or become ill as a result of participating in this research project. This does not waive any of your legal rights nor release any claim you might have based on negligence.

Confidentiality
The project's research records may be reviewed by the study sponsor, AOptix, and by departments at Purdue University responsible for regulatory and research oversight.

Iris image data collected will be compiled and be delivered to the National Institute of Standards and Technology (NIST) as part of the IREX II test. This data will be made publically available from the NIST website for researchers to download so that they can test their algorithms. No identifying information except for the iris image will be sent to NIST. All the data will be maintained indefinitely for research by the Purdue University's Biometric Standards, Performance & Assurance (BSPA) Laboratory. Only authorized researchers from Purdue's BSPA laboratory AND AOptix involved in biometrics research will have access to the database. The data is does not contain any personally identifiable information, except for images of the iris and the demographic information above. Consent forms will be stored in the Biometric Standards, Performance and Assurance (BSPA) Laboratory.

For the purposes of distributing your payment for completing the study, you understand that your name, social security number, and address shall be provided to the business office of Purdue University. Neither the BSPA laboratory nor AOptix will maintain your social security number after you complete the study.

Voluntary Nature of Participation
You do not have to participate in this research project. If you agree to participate you can withdraw your participation at any time without penalty.

Contact Information
If you have any questions about this research project, you can contact Stephen Elliott elliott@purdue.edu. If you have concerns about the treatment of research participants, you can contact the Committee on the use of Human Research Subjects at Purdue University, Ernest C. Young Hall, 10th Floor, Room 1032, 155 S. Grant Street. West Lafayette, IN 47907-2114. The phone number for the Board's secretary is (765) 494-5942. The email address is irb@purdue.edu.

Documentation of Informed Consent
I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research project and my questions have been answered. I am prepared to participate in the research project described above.

______________________________ __________________
Participant's Signature Date

____
Participant's Printed Name

______________________________ __________________
Researcher's Signature Date

Appendix B Consent Form for the 2012 Data Collection

-Open to Enrollment on 31-MAY-2012 Purdue IRB Protocol #: 1205012266 - Expires on: 30-

RESEARCH PARTICIPANT CONSENT FORM
Multi-modal aging database collection for biometric research

Stephen J. Elliott, PhD
Purdue University
Department of Technology, Leadership and Innovation

Purpose of Research

This research will be used to test the performance of several biometric systems. An example of a biometric is a fingerprint, iris, signature and is used to identify individuals. Outcomes of this study will help in furthering the understanding of biometric system performance over time and how to improve such systems. This research is being conducted with other researchers from Bion Biometrics in Canada, and a research group at the University of Kent in the United Kingdom.

Specific Procedures

As a participant, you will be provided with a copy of this informed consent form to read and sign if you choose to participate. You will go through six stations which will collect information from you.

Station 1

At station 1, demographic information will be collected. This includes ethnicity, first name, middle name, last name, work category, contact information such as e-mail, phone, whether you have been in a biometric study before and what type of study (fingerprint, iris etc.), what your dominant hand is (the one you write with typically), and whether you wear contact lenses (specifically hard, patterned, soft, and/or colored). We will also ask whether you have any movement or muscle soreness that we would need to know about, such as arthritis or rheumatism at this time. Information such as your name, contact information will be kept separate in another database. We collect this information to make sure we can contact you in the future if you wish. Your signature at station 1 will be stored in a separate database.

Station 2

At station 2, you will have some skin characteristics measured, including temperature, skin texture, pigmentation, oiliness, moisture, elasticity, skin color and keratin – the outer layer of the skin. The device will take a picture of your dominant index finger. This information is used to understand how your skin can affect the performance of a biometric fingerprint reader. For example, dry fingers can cause lighter images and moist fingerprints cause darker images. We will note whether you have any head coverings on.

Station 3

At station 3, we will scan your driver's license and/or passport / visa. This is because we are measuring aging and we can get an official issue date. The following information is captured by the scanner: photo, signature, issue date, sex, height, date of birth, State of issue, country. We need this information in order to understand how aging affects your signature. For example, if your driver's license was issued five years ago, we can measure the photograph from your driver's license against the photograph taken at Station #6. We will delete the other information from the record. This is to maintain your privacy. You may also bring in current photographs taken from CVS or Walgreens as passport photos. These should have been taken within the last six months. For reimbursement you should bring a valid receipt. You will then move on to station 4.

Station 4

Here you will have your fingerprints taken using a number of different sensors. We will take 6 images from your index finger, middle finger on both hands. We will try up to 18 times for each finger. If we cannot get six images in 18 tries, you will move onto the next fingerprint sensor.

Initials Date

Approved on 31-MAY-2012 - MIT IRB Protocol #: 1205012266 - Expires on: 30-MAY-2013

Station 5

The next station is the iris station. This is set up in a similar process that you would find in an immigration hall. This particular camera is used for border security at an airport in London, England. You will walk up to the iris camera following the arrows on the floor, and standing in a red rectangular box. We will measure how far away you are from the camera. The camera will take a photograph of your eyes. We will ask you to repeat this twenty times.

Station 6

At station 6, you will have aphotograph of your face taken three times.

Station 7

At station 7, we will measure your fingerprints again, this time taking all four fingers at the same time, followed by the thumbs. This is set up in a similar process that you would find in an immigration hall. This particular device is used for border security in many international airports. We will repeat this three times.

Duration of Participation

This study consists of up to 8 visits over a period of a year, lasting approximately 45 minutes for visit 1, 45 minutes for visit 2 , 10 minutes for visits 3-7 and 20 minutes for visit 8. You do not have to participate in visits 3-8 if your schedule does not permit. Visit 8 can be scheduled up to 8 months away. This is to get another set of aging data.

Risks

This study poses minimal risk to you: no more than occurs in everyday activities. Biometric images will be collected without identifying information. The iris biometric images collected in this study will be included in a dataset will be delivered to AOptix who manufacture the device. The other data will be analyzed by the research group in Canada and United Kingdom. This data will not contain any personally identifiable information.; however there is risk that you could be identified causing a breach of confidentiality.

Benefits

There are no benefits to you as a participant. However, the administrator of fingerprint scanners may benefit from the result of this study as it will allow researchers to recommend guidelines to improve performance.

Compensation

You will be paid if you complete visits 1 and 2 ($20/visit) and 8 of the research study ($15). You will be paid an additional $5 separately at the completion of visit 2-7, for a maximum of $80. You will not be compensated for early withdrawal. All the collected information will be destroyed if you decide to withdraw from the study..

Confidentiality

The project's research records may be reviewed by the study sponsor, Department of Homeland Security (DHS) and AOptix, and by departments at Purdue University responsible for regulatory and research oversight.

Only authorized researchers from Purdue's BSPA laboratory AND AOptix involved in biometrics research will have access to the database. The data is does not contain any personally identifiable information, except for images of the iris and the demographic information above. Consent forms will be stored in the Biometric Standards, Performance and Assurance (BSPA) Laboratory. For the purposes of distributing your payment for completing the study, you understand that your name, social security number, and address shall be provided to the business office of Purdue University. Neither the BSPA laboratory nor AOptix or DHS will maintain your social security number after you complete the study. The database is locked in a secure location, with limited access rights to research team members only.

Voluntary Nature of Participation

You do not have to participate in this research project. If you agree to participate you can withdraw your participation at any time without penalty.

Initials Date

If you are interested in being contacted for future studies, please sign and date below.

_______________________ _______________
Participant's Signature Date

Appendix C Recruitment Email for 2012 Visit 2 and Previous Subjects

Hello *|FNAME|*

I'd like to thank you for taking part in the iris biometric study in 2009 and 2010. In a recent study conducted in the lab, we asked whether participants would like to see the results of the studies that they participated in. So not to overwhelm your inbox with information you may not want, we have created a sign up sheet for this information.Pl (http://eepurl.com/kw-x1) ease click here for this link. (http://eepurl.com/kw-x1) We know a number of you have graduated and moved on from the Lafayette / West Lafayette area, but if you are still around, please feel free to drop by. We will be moving into a new lab in June / July this year, and scheduling an open house. Your help in data collection enables us to provide opportunities for graduate and undergraduate student research, on behalf of those students past and present, many thanks for your support.

Sincerely,

Steve Elliott
Associate Professor, Biometrics Lab
Purdue University

Appendix D Recruitment Poster for 2012 Data Collection

PERSONS NEEDED FOR BIOMETRIC AGING STUDY

The Biometrics Lab at Purdue University is looking for people over the age of 18 to participate in a study to see how fingerprint sensors perform.

Participants will be asked to participate in up to 8 sessions over the period of eight months.

You will be compensated up to a maximum of $80

To register online go to www.bspalabs.org/register

IRB#

Aging Study $85 http://www.bspalabs.org/register.
Aging Study $85 http://www.bspalabs.org/register.
Aging Study $85 http://www.bspalabs.org/register.
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Aging Study $85 http://www.bspalabs.org/register.

Figure D.1. Tear away recruitment poster

Appendix E Reminder Email for Visits 4 and 5 in 2012 Data Collection

Hello <insert subject name>,

Based on our records, you have been processed through our Aging Study Visit <insert visit n>, but have not yet been processed through Visit <insert visit n+1>. We would be happy for you to return for Visit <insert visit n+1> of this study as well as the rest of them. Due to either not having your schedule or the scheduling software was unavailable, we do not have a <insert visit n+1> visit scheduled for you. It would be great for you to return, so if you are still willing to return for multiple visits please visit the URL below and sign up for Visit <insert visit n+1> between <insert appropriate date range>, or email Jacob Hasselgren (jahassel@purdue.edu) three times that best fit your schedule so he can schedule you. We look forward to hearing from you and thanks for your participation.

http://www.snapappointments.com/listing/2oH

If you are receiving this email and the above isn't true or you had another reason for not signing up, please disregard or reply to stop any further emails.

Regards,

Jacob Hasselgren
BSPA Labs
Graduate Researcher

Appendix F Habituation Survey Questions

Question 1

1. Please provide your age:

Please provide the number of years of experience you have had in biometrics:

Question 2

2. How would you define habituation in general?

Question 3

3. Do you think habituation has an effect on biometric systems?

- Yes
- No

If yes, why do you think it is important? If no, why not?

Question 4

4. Do you believe that acclimation and habituation are synonyms?

- Yes
- No

If not, what is the difference?

Question 5

5. Do you believe the influence of a system administrator through feedback or initial instructions affect habituation?

- Yes
- No

If so, in what ways does such influence affect habituation? If not, why not?

Question 6

6. Do you believe there are different phases of habituation that can occur over time?

- Yes
- No

How would you differentiate the different phases?

Question 7

7. Do you believe habituation affects the quality of a given sample?

- Yes
- No

If so, in what ways do you think habituation affects the quality? If not, why not?

Question 8

8. Do you believe habituation directly affects the performance of a given sample?

- Yes
- No

If so, in what ways do you think habituation affects the performance? If not, why not?

Question 9

9. Dishabituation is defined as "the restoration of a habituated response by extraneous stimulation." In biometric terms, your habituated presentation changes when a different stimulus is used.

Do you believe that "dishabituation" occurs?

- Yes
- No

If so, what do you believe causes dishabituation?

Question 10

10. Would the classification of levels of habituation be beneficial to the implementation of a biometric system, either in a lab environment or corporate setting?

- Yes
- No

If so, explain the practicality of a numerical classification system. (For example, a level 1 habituated user is novice while a level 5 habituated user is the most experienced)

Question 11

11. Many factors exist that may affect or habituation in a subject. Some of these factors may be more influential on habituation than others.

Please rate the following factor's influence on habituation (0 being "not influential at all" and 10 being "very influential):

	0	1	2	3	4	5	6	7	8	9	10
Number of visits device is used											
Number of interactions per visit											
Number of attempts per visit											
Length of time between each visit											
Complexity of device interaction											
Subject IQ											
Test administrator feedback											
Training given to subject											
Change of environment											
Time-on-task											

12. If there was any biometric modality that you based the above results on, please provide the name of that modality:

Appendix G <u>Sample AOptix Process Log and Computation Breakdown</u>

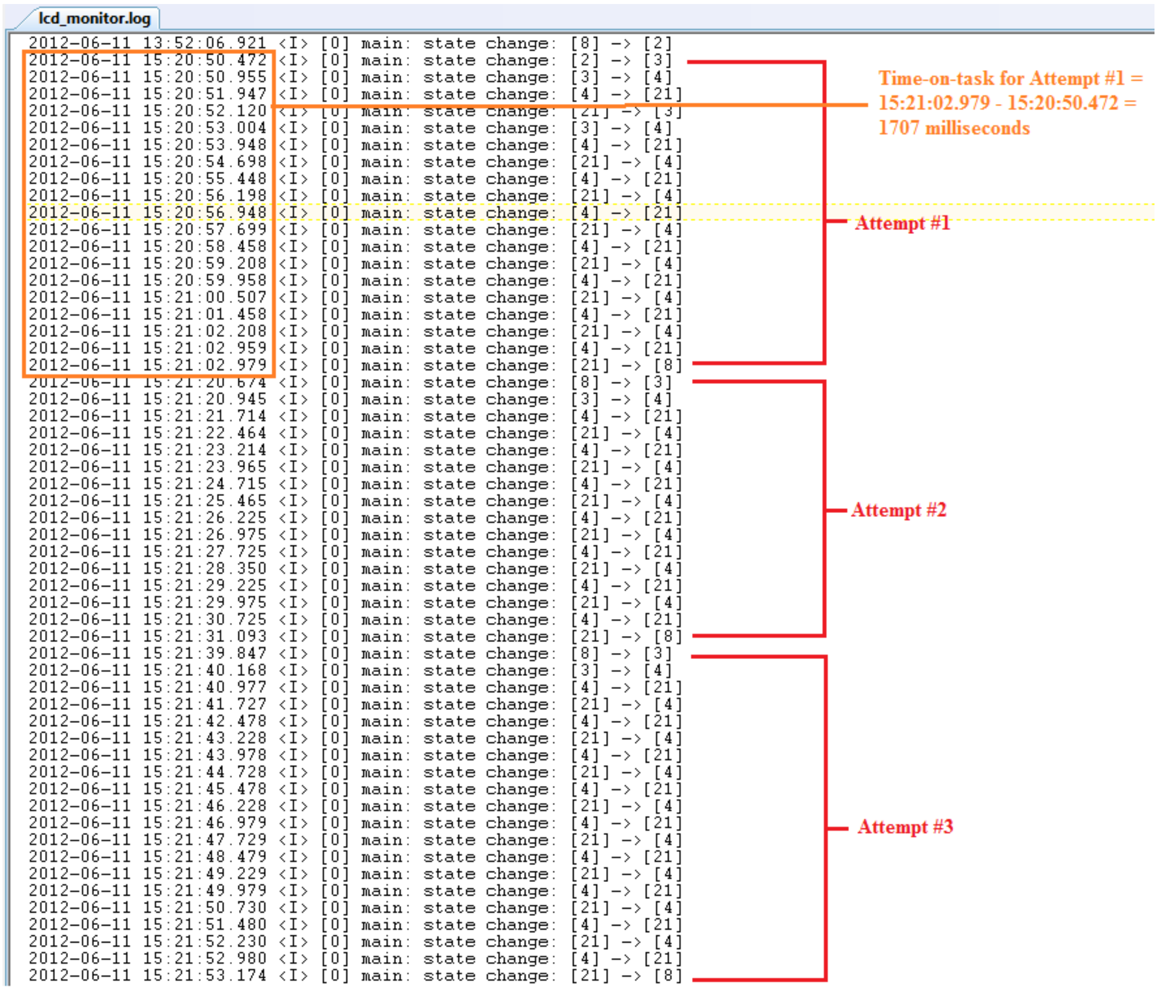

Figure G.1. Sample Aoptix process log and computation breakdown

Appendix H Full Habituation Survey Responses

Table H.1. *Full habituation survey responses*

Question 1: Please provide your age and number of years you have been in biometrics:		
Respondent	Age	Years of Experience
R1	61	29
R2	55	18
R3	40	19
R4	40	12
R5	31	10
R6	43	12
R7	30	8
R8	53	20
R9	28	4
R10	43	8
R11	62	25
R12	52	13
R13	38	15

Question 2: How would you define habituation in general?	
Respondent	Response

R1	The agreed definition in ISO/IEC SC37 SD 2 is CN: capture subject habituation OED: make or become accustomed to something Defn: degree of familiarity of a biometric capture subject with the biometric capture process NOTE 1:A biometric capture subject with substantial familiarity with the biometric capture process is referred to as a habituated capture subject. NOTE 2: Habituation may be acquired through system use or observation of use by others Capabilities acquired through use or observation Applies to biometric capture subject Degree of familiarity/experience Applies to one specific system only Leads to different behaviours during use Affected by frequency of use and time since last use Hursley 2013
R2	Familiarity over time of a user/subject with the process of using a biometric system (including interaction with the sensor) for identity verification, identification, or other purpose.
R3	Becoming familiar with a process or stimulus which may or may not lead to complacency and accuracy of task execution.
R4	Habituation is where a user has become accustomed with a process through regular usage.
R5	Habituation in the process of getting used to an activity due to the repetitive nature of activity which results in requiring less concentration and time to complete the activity.
R6	becoming accustomed or used to something
R7	Habituation is the process by which people become more familiar an efficient performing a particular task.
R8	being familiar with the use of biometric devices
R9	Some behaviour that we don't wanna change
R10	stay in a place for a relatively long time

R11	In the context of biometrics: A process in which a subject becomes progressively more familiar with the use of a biometric collection device and is therefore capable of making more uniform presentation to the device and thereby producing higher quality samples with lower variance. However, it is possible that a user can become complacent over time and present in a fashion that reduces the quality of samples. This is especially important in academic collections which do not include immediate feedback to the subject and some form of reward for high quality capture. -- compare with an access system were subjects presenting a low quality sample are immediately penalized with a denial of entry.
R12	The efficiency increase of human-machine interaction through familiarization improvements based upon repetition. Habituation improvements include reduction in the number of attempts and/or the reduction in dwell time required for a successful capture event.
R13	The process through which a subject/user gains familiarity with a biometric capture method in order to provide usable data.

Question 3: Do you think habituation has an effect on biometric systems? If so, why do you think its important? If no, why not?

Respondent	Response to Yes/No	Response to follow up
R1	Yes	This has been established in several studies. I think that the Germans were first to show results with iris data about 8 years ago.
R2	Yes	Increases in habituation generally result in improved biometric system performance (both speed and accuracy) and reduction in user/system errors.
R3	Yes	Habituation may lead to a relaxation in the execution of events associated with the interaction/donation of a biometric sample.
R4	Yes	It is important because habituated users can reduce biometric system error rates due to their knowledge of how to use the system.

R5	Yes	All biometric systems require human subjects to interact with it to initiate the capture process. This interaction process undergoes the habituation effect that can lead to lesser interaction time, higher quality of captured sample or both.
R6	Yes	Habituation allows for efficient and accurate interaction with a biometric system.
R7	Yes	The users level of habituation with the system should be a direct linear relationship with performance on the system.
R8	Yes	Habituation will reduce the chance of false rejection.
R9	Yes	Human's behaviour is a important factor, as well as habituation behavior.
R10	-	-
R11	Yes	See definition
R12	Yes	Improves througput and can reduce "failure to acquire" events
R13	Yes	Very generally speaking, for some biometrics it is plausible that habituation will result in lower FTE rates and FNMRs.

Question 4: Do you believe that habituation and acclimation are synonyms? If not, what is the difference?

Respondent	Response to Yes/No	Response to follow up
R1	No	"Acclimation" has not been considered by SC37
R2	Yes	Though I said yes, you could argue that acclimation is at the beginning of the learning curve (high slope area) whereas habituation extends beyond throughout the period of use.
R3	No	I see acllimation to be a positive process whereby a subject is becoming familiar with a device by adjusting to particular usability issues. Habituation is a negative process based on over-familiarity
R4	No	Acclimation is adapting to an environment, habituation is becoming accustomed to a process.

R5	No	Acclimation implies a change in inherent behavior or physiology of a human subject as it adapts to its environment. Habituation implies a learning process which changes only the behavior of the human subject.
R6	Yes	Perhaps, in the context of biometric system, the 2 terms refer to the same concept.
R7	No	I believe acclimation has more to do with the user becoming familiar and comfortable with the system in terms of personal feelings and preference. Habituation deals more with repetition, practice and can be measured by speed, accuracy etc.
R8	Yes	-
R9	No	Habituation is hard to change, but acclimation is not difficult.
R10	No	for acclimation, someone was born there, and grew up there, but for habituation, may not bear there.
R11	No	Not sure
R12	Yes	-
R13	No	Acclimation expresses the process that includes formal training as well. Habituation is more of an expression of user's state.

Question 5: Do you believe the influence of a system administrator through feedback or initial instructions affect habituation? If so, in what ways does such influence affect habituation? If not, why not?”

Respondent	Response to Yes/No	Response to follow up

R1	Yes	Impact of system conditions, particularly the operational threshold, has broadly understood. This is not quite the correct question because the system attendant (see ISO/IEC 2382-37) is more important than the administrator in this regard. See J.L. Wayman, A. Possolo, and A.J. Mansfield, “A Modern Statistical and Philosophical Framework for Uncertainty Assessment in Biometrics" (accepted for 2013 publication in IET Biometrics)
R2	Yes	Good instructions can accelerate habituation.
R3	Yes	It depends whether the subject habituates to the instructions of the system admin! I would guess that the more 'scripted' the feedback the larger the effect. A good analogy is the emergency instructions of aircraft - do frequent flyers actually take this in everytime?
R4	Yes	It can speed up habituation as may help users learn best approaches to the process faster.
R5	Yes	The quality of feedback provided by the administrator has an impact on the time to get habituated. It is similar to the quality of instruction and how much a student learns.
R6	No	Instruction and feedback help with a better capture and allow for habituation, but by themselves do not `help' habituation. A use is either habituated or in the process and not habituated.
R7	Yes	It has a direct impact on the user's behavior and overall performance. they are no longer thinking on their own
R8	Yes	Initial instruction by a system admin will reduce the time (or duration) of habituation.
R9	Yes	For example, in a fingerprint recognition system, a admin may ask users to press sensor very hard, those users habituation can be affect.
R10	-	-
R11	Yes	See definition

R12	Yes	Creates an expectation on behalf of the user on how the system will operate, the appropriate way to interact with the device,.
R13	Yes	Well-constructed advice from an administrator can shorten the time in which the user becomes habituated, eliminating the need for certain experimentation the user may otherwise have to go through.

Question 6: Do you believe there are different phases of habituation that can occur over time? If so, how would you differentiate the different phases?

Respondent	Response to Yes/No	Response to follow up
R1	-	Unknown
R2	Yes	Initial (learning), confident usage, sloppy usage
R3	Yes	I'm sure there are, but I'm not sure how these are defined - this is a research question!
R4	Yes	Use category labels such as early, medium, long-term habituation.
R5	Yes	Loosely I would differentiate the phases as : Understanding the information, Contextualizing the information, Internalizing the information, Maintaining the information
R6	Yes	-
R7	Yes	At a minimum, I believe their are 2 phases. the first were the user's habituation level is rapidly increasing to a certain acceptable level and then the speed of habituation levels off into a flat or minimal improvement phase. The differentiate is the point at which the interaction is acceptable to gain access or meat a necessary threshold.
R8	No	-
R9	No	-
R10	-	-
R11	Yes	See definition

R12	Yes	Unhabituated - no knowledge of the device, its operation or expected outcomes; Novice - Limited knowledge of, or experience with the device or expected outcomes; Habituated - Experienced user of the device that consistantly achieves the expected outcome
R13	Yes	By the before- and after- periods of the point at which the user's methodology can be considered to have become, in a manner of speaking, innate.

Question 7: Do you believe habituation affects the quality of a given sample? If so, in what ways do you think habituation affects the quality? If not, why not?

Respondent	Response to Yes/No	Response to follow up
R1	-	What is “quality”?
R2	Yes	Generally, habituation results in the user interacting correctly with the system/sensor (e.g., finger placement) which results in a higher quality sample being captured.
R3	Yes	Incorrect/complacent presentation towards a capture device
R4	Yes	Habituated users should on average present higher quality samples, as they have become accustomed as to how best use the system.
R5	Yes	It affects quality because it reduces the ambiguity of how a user should interact with the sensor, as well as how to compensate for any extraneous factors that can affect quality (like dirt on finger, wearing glasses, etc)
R6	-	It could - it can diminish poor quality captures due to poor presentation. Low fidelity (e.g. heavy compression) or low quality capture device or low character are not affected by habituation of lack of.
R7	Yes	higher habituation should result in higher quality.
R8	Yes	As a user is more habituated to a device, the quality of sample will become better.
R9	Yes	In fingerprint recognition system, the angle, force or duration when ones finger touchs sensor.

R10	Yes	-
R11	Yes	See definition
R12	Yes	The user understands what is expected during the presentation and thus can often provide the sample within the "sweet spot" of the device versus an unhabituated user that often will provide a sample closer to the edge of the tolerance level of the device
R13	Yes	In broad terms, certain features (very general definition of the term) can become exposed more heavily in certain individuals due to habituation.

Question 8: Do you believe that habituation directly affects the performance of a given sample? If so, in what ways do you think habituation affects the performance? If not, why not?

Respondent	Response to Yes/No	Response to follow up
R1	-	What is the "performance of a given sample"? How is a single sample said to "perform"?
R2	Yes	Yes, as performance is usually correlated with sample quality.
R3	Yes	As question 7.
R4	Yes	Habituated users should be able to present higher quality samples and interact with the process better, on average, than non-habuitated users unfamiliar with the process.
R5	Yes	Habituation has an impact on sample quality, which affects how much the sample contributes to FTA, FAR and FRR of the system.
R6	-	It could - poor presentation (nonfrontal gaze or capture of tip of fingerprint) will result in low performance.
R7	Yes	higher habituation should be high performance because the system is being used as it is inteded to.
R8	Yes	More habituation -> Better sample quality -> Less FRR

R9	Yes	-
R10	-	-
R11	Yes	See definition
R12	Yes	Depends on the operating/quality assessment charectaristics of the device
R13	Yes	Same as the prior answer

Question 9: Dishabituation is defined as "the restoration of a habituated response by extraneous stimulation." In biometric terms, your habituated presentation changes when a different stimulus is used. Do you believe that “dishabituation” occurs? If so, what do you believe causes dishabituation?

Respondent	Response to Yes/No	Response to follow up
R1	-	What is the source of this definition?
R2	Yes	Changes in user interface, environment, etc.
R3	Yes	I wanted to answer 'I'm not sure' - I guess a change in UI/instructions/feedback may improve things
R4	No	-
R5	Yes	Dishabituation can occur over time due to the lack of repeating the tasks involved in completing an activity to which you were earlier habituated. In my opinion, a person can attain a certain degree of habitutation but will start regressing from that state if the activity is not repeated at periodic intervals.
R6	-	Maybe dishabituation can happen. I cannot quit understand the text above :(sorry.
R7	Yes	Decreased level of regular interaction, or long gaps of no interaction.
R8	Yes	The time elapsed since the last usage. Use of different types of sensors (ex: change from an area type sensor to a swipe type sensor)

R9	No	-
R10	-	-
R11	Yes	See definition
R12	-	-
R13	-	-

Question 10: Would the classification of levels of habituation be beneficial to the implementation of a biometric system, either in a lab environment or corporate setting? If so, explain the practicality of a numerical classification system. (For example, a level 1 habituated user is novice while a level 5 habituated user is the most experienced)

Respondent	Response to Yes/No	Response to follow up
R1	No	Possibly, but this may be a multi-faceted phenomenon for which a single metric is not sufficient.
R2	Yes	Most utility would be in planning for administrative assistance to users based on their habituation level.
R3	Yes	It will provide metrics for cross-comparison of systems.
R4	Yes	-
R5	Yes	Such a system can be used to determine exactly what type of feedback needs to be provided to the user (more for a less habituated user). This would also be useful in determining what type of remediation processes to use in case of an error that occurs (analogous to level 1 vs. level 3 technical support)
R6	No	-
R7	Yes	Just as in rapid tolling on the highway or express lines at the store, segmenting out level 5 biometric users who need little to no admin interaction will be much quicker on their own instead of lumping them in with level 1 users. Furthermore, studying level 1 users for faults or problems can lead to better user education.

R8	Yes	Level 1: novice Level 2: experienced Level 3: Sufficiently experienced
R9	Yes	3 levels are enough i think
R10	-	-
R11	Yes	I see no practical way of doing this.
R12	-	-
R13	-	-

Question 11: Many factors exist that may affect or habituation in a subject. Some of these factors may be more influential on habituation than others. Please rate the following factor's influence on habituation (0 being "not influential at all" and 10 being "very influential):

Respondent	Response (factor #1: from 0-10, factor #2: rank from 0-10, etc…)
R1	-
R2	Number of visits device is used: 10, Number of interactions per visit: 9, Number of attempts per visit: 9, Length of time between each visit: 9, Complexity of device interaction: 9, Subject IQ: 10, Test administrator feedback: 9, Training given to subject: 9, Change of environment: 8, Time-on-task: 9
R3	Number of visits device is used: 9, Number of interactions per visit: 7, Number of attempts per visit: 5, Length of time between each visit: 8, Complexity of device interaction: 9, Subject IQ: 2, Test administrator feedback: 7, Training given to subject: 6, Change of environment: 5, Time-on-task: 3
R4	Number of visits device is used: 10, Number of interactions per visit: 10, Number of attempts per visit: 10, Length of time between each visit: 8, Complexity of device interaction: 9, Subject IQ: 7, Test administrator feedback: 8, Training given to subject: 9, Change of environment: 6, Time-on-task: 8
R5	Number of visits device is used: 7, Number of interactions per visit: 9, Number of attempts per visit: 9, Length of time between each visit: 6, Complexity of device interaction: 10, Subject IQ: 1, Test administrator feedback: 8, Training given to subject: 9, Change of environment: 6, Time-on-task: 5

R6	Number of visits device is used: 6, Number of interactions per visit: 7, Number of attempts per visit: 8, Length of time between each visit: 6, Complexity of device interaction: 7, Subject IQ: 9, Test administrator feedback: 5, Training given to subject: 5, Change of environment: -, Time-on-task: 6
R7	Number of visits device is used: 7, Number of interactions per visit: 9, Number of attempts per visit: 9, Length of time between each visit: 10, Complexity of device interaction: 5, Subject IQ: 9, Test administrator feedback: 8, Training given to subject: 9, Change of environment: 5, Time-on-task: 5
R8	Number of visits device is used: 5, Number of interactions per visit: 8, Number of attempts per visit: 9, Length of time between each visit: 6, Complexity of device interaction: 3, Subject IQ: 5, Test administrator feedback: 7, Training given to subject: 10, Change of environment: 1, Time-on-task: 0
R9	Number of visits device is used: 6, Number of interactions per visit: 6, Number of attempts per visit: 6, Length of time between each visit: 6, Complexity of device interaction: 7, Subject IQ: 3, Test administrator feedback: 9, Training given to subject: 7, Change of environment: 5, Time-on-task: 6
R10	-
R11	Number of visits device is used: 10, Number of interactions per visit: 10, Number of attempts per visit: 10, Length of time between each visit: 10, Complexity of device interaction: 10, Subject IQ: 10, Test administrator feedback: 10, Training given to subject: 10, Change of environment: 10, Time-on-task: 10
R12	-
R13	-

Question 12: If there was any biometric modality that you based the above results on, please provide the name of that modality:

Respondent	Response
R1	-
R2	-

R3	Signature
R4	-
R5	fingerprint, face and iris
R6	-
R7	Fingerprint
R8	Fingerprint
R9	-
R10	-
R11	-
R12	-
R13	-

Appendix I Bar Charts of Ethnicity and Age for All Visits

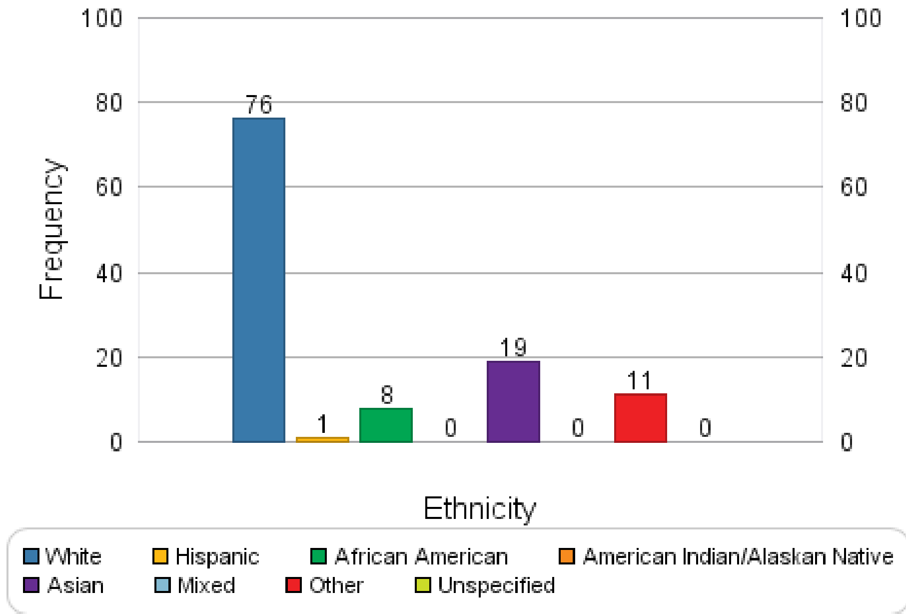

Figure I.1. Bar chart of Visit 1 ethnicity distributions for the 2012 data collection

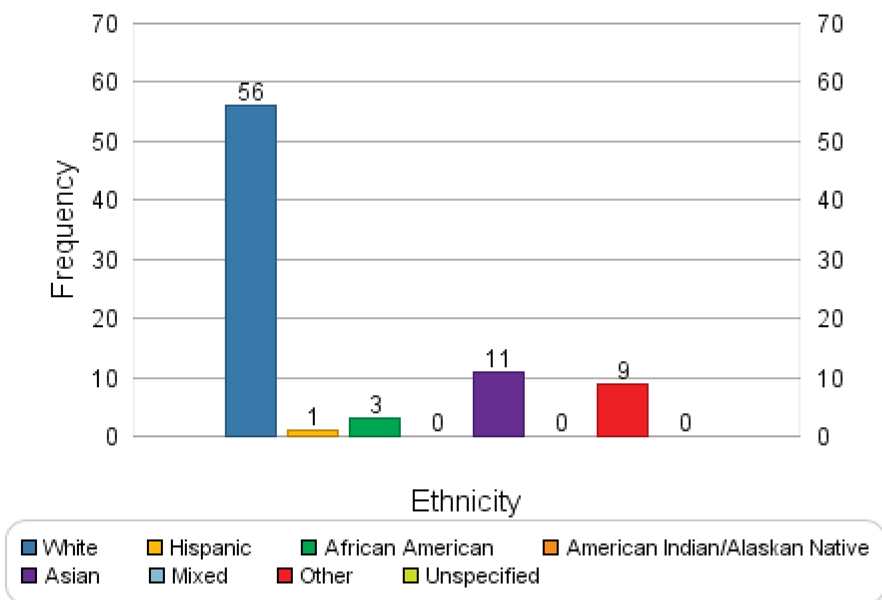

Figure I.2. Bar chart of Visit 2 ethnicity distributions for the 2012 data collection

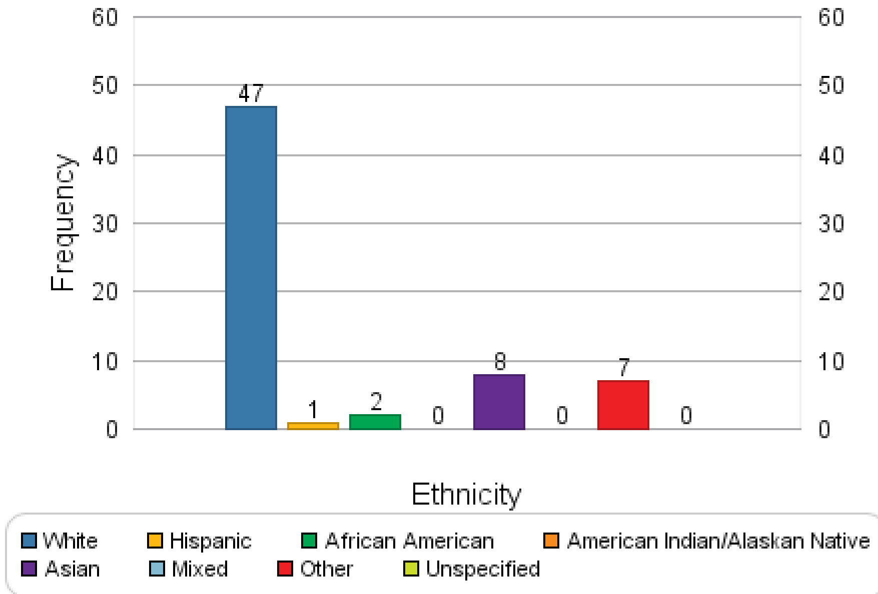

Figure I.3. Bar chart of Visit 3 ethnicity distributions for the 2012 data collection

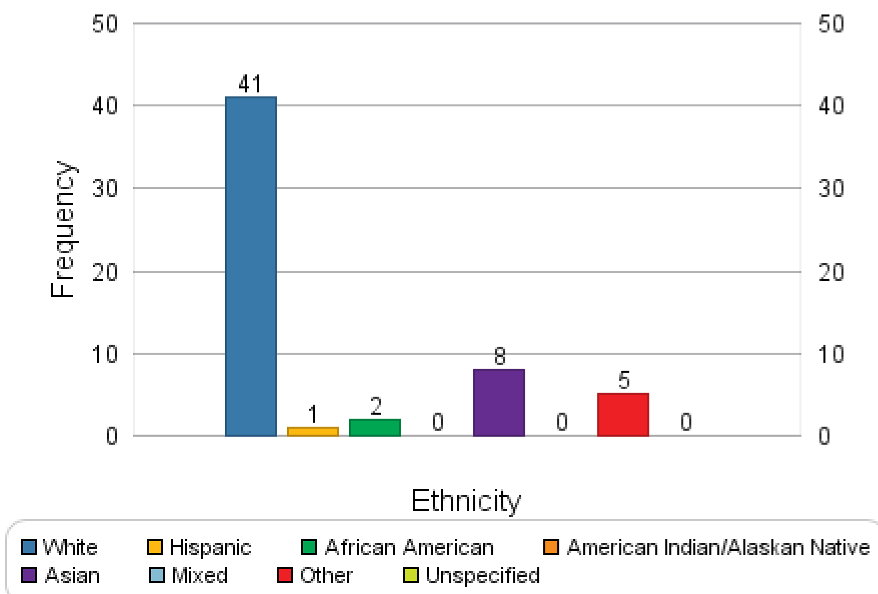

Figure I.4. Bar chart of Visit 4 ethnicity distributions for the 2012 data collection

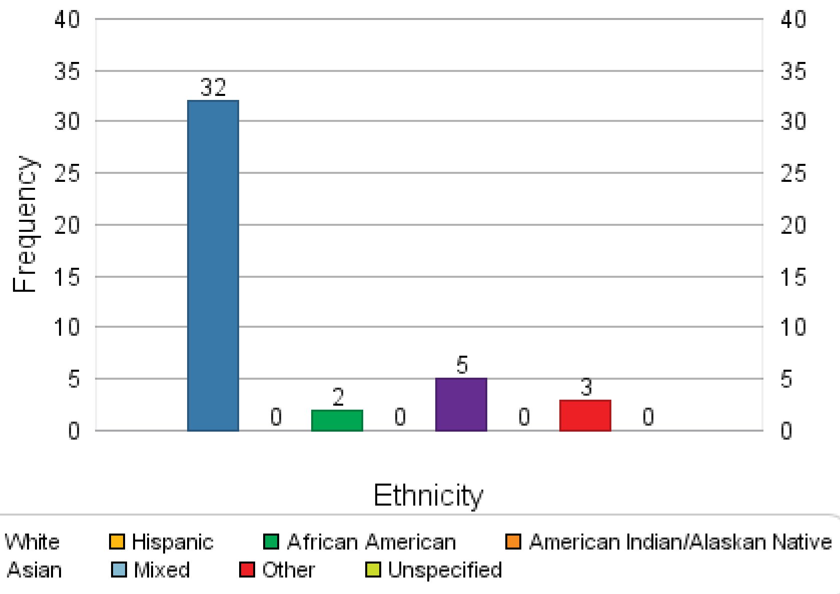

Figure I.5. Bar chart of Visit 5 ethnicity distributions for the 2012 data collection

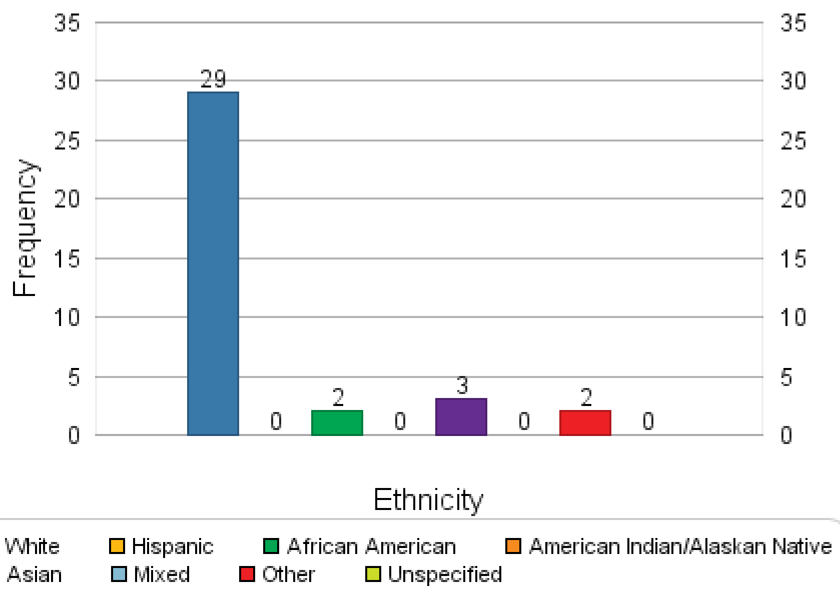

Figure I.6. Bar chart of Visit 6 ethnicity distributions for the 2012 data collection

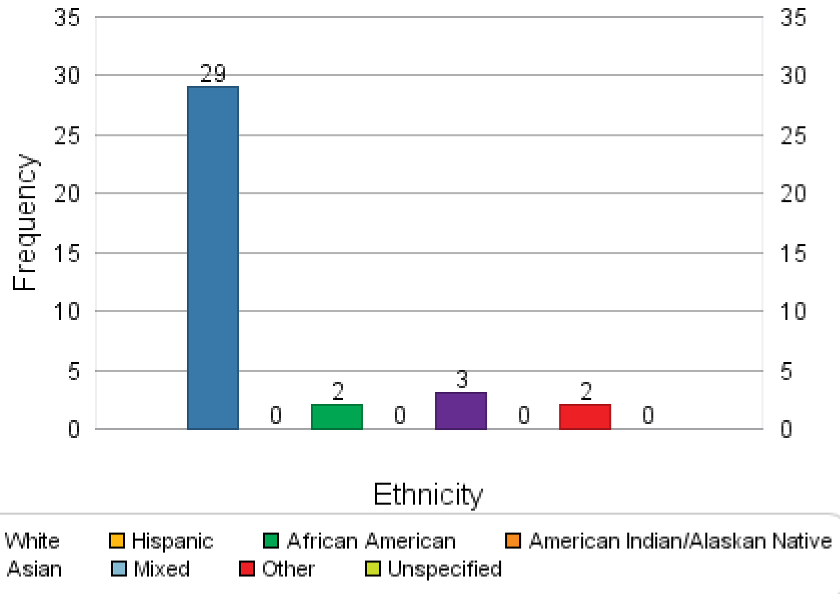

Figure I.7. Bar chart of Visit 7 ethnicity distributions for the 2012 data collection

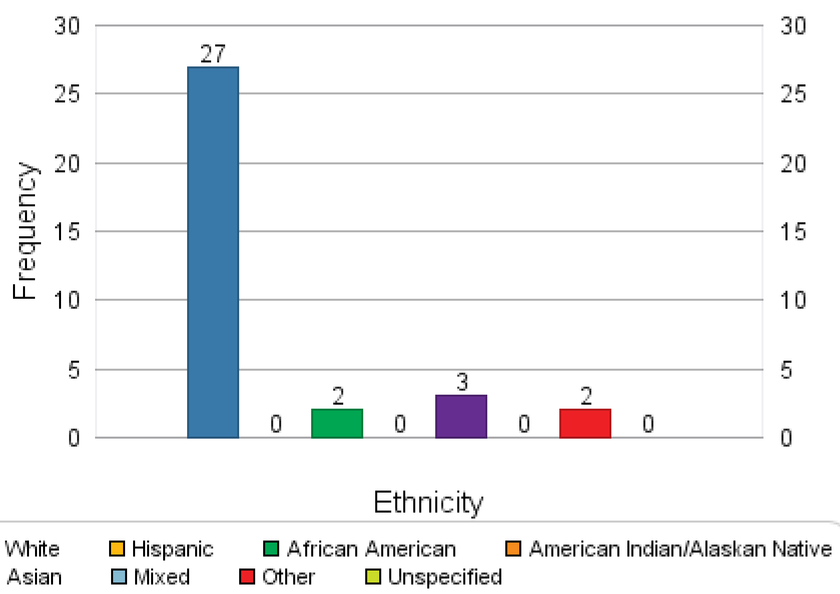

Figure I.8. Bar chart of Visit 8 ethnicity distributions for the 2012 data collection

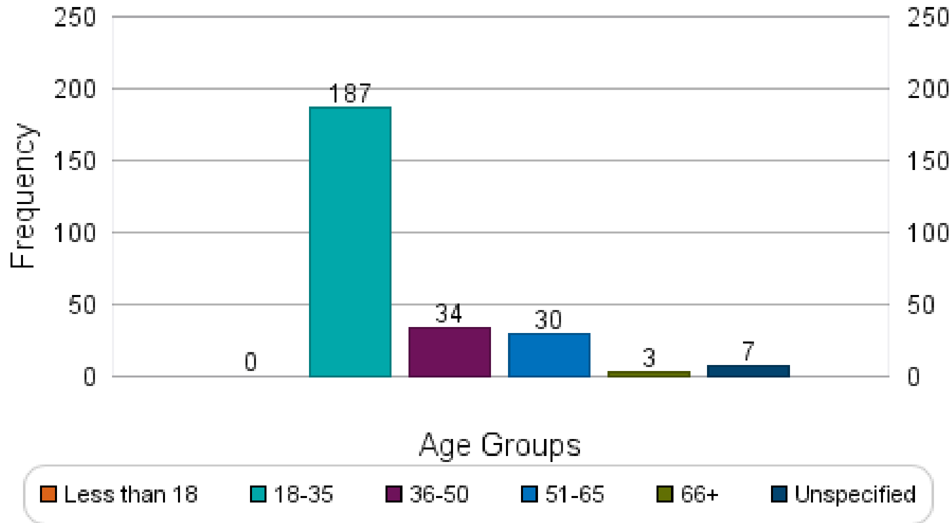

Figure I.9. Bar chart of Visit 1 ethnicity distributions for the 2010 data collection

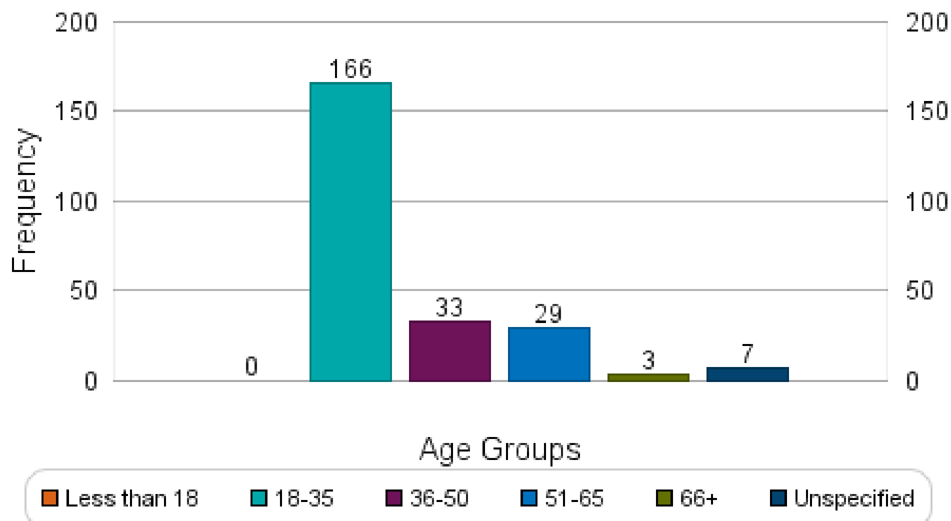

Figure I.10. Bar chart of Visit 2 ethnicity distributions for the 2010 data collection

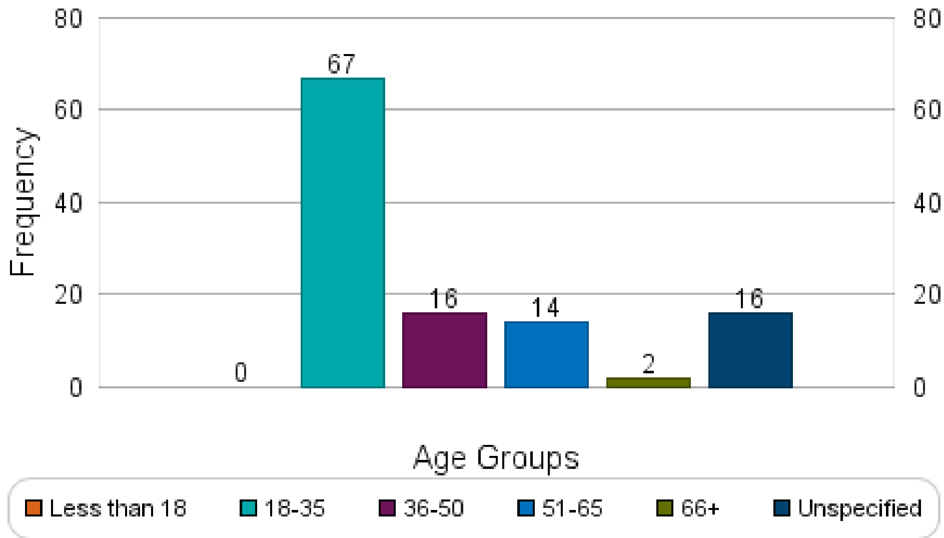

Figure I.11. Bar chart of Visit 1 ethnicity distributions for the 2012 data collection

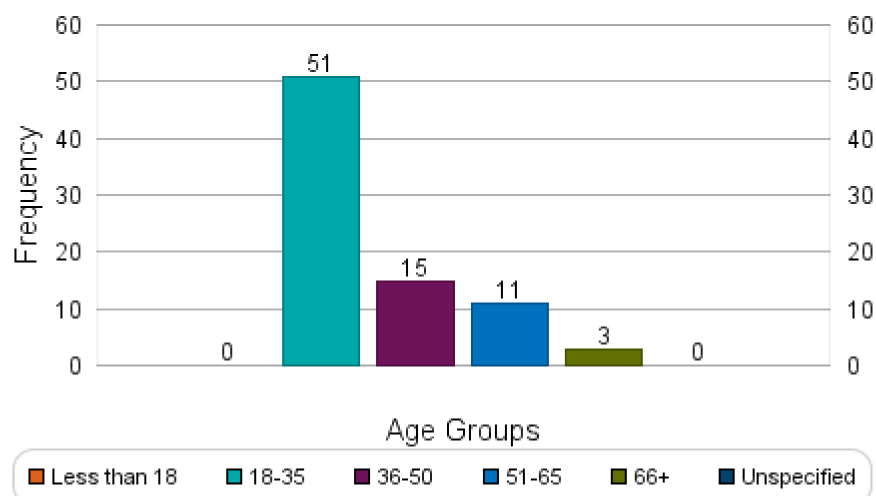

Figure I.12. Bar chart of Visit 2 ethnicity distributions for the 2012 data collection

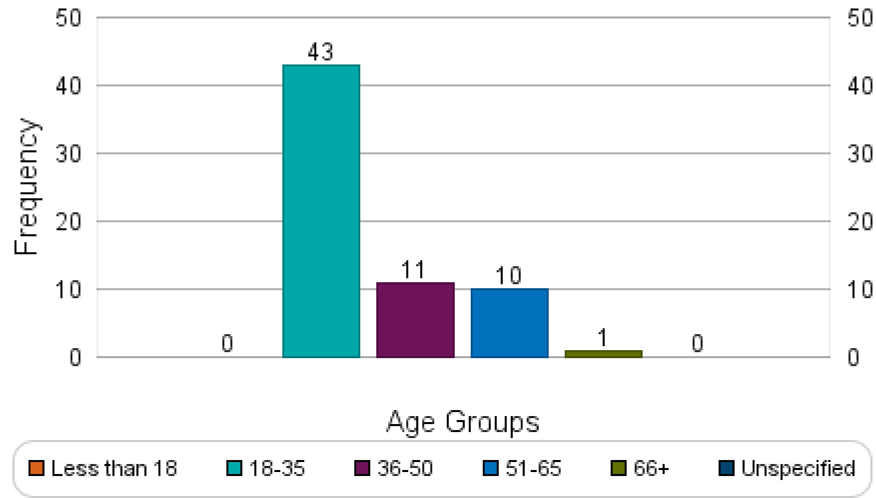

Figure I.13. Bar chart of Visit 3 ethnicity distributions for the 2012 data collection

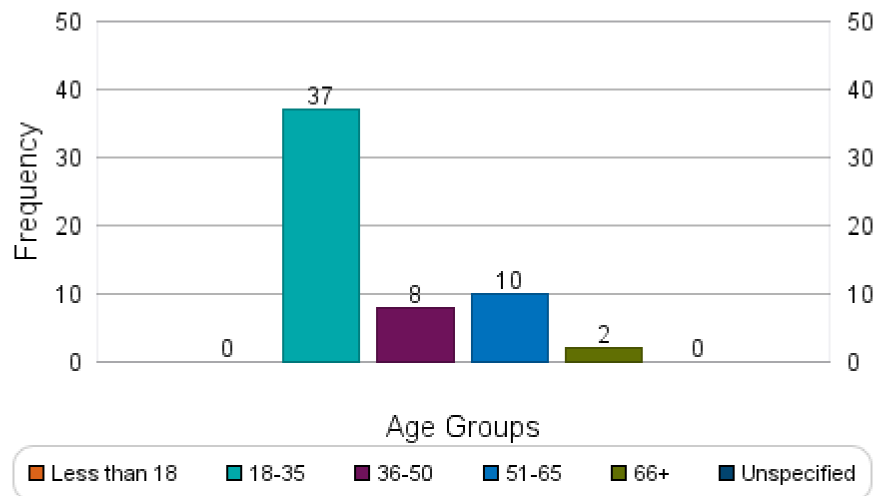

Figure I.14. Bar chart of Visit 4 ethnicity distributions for the 2012 data collection

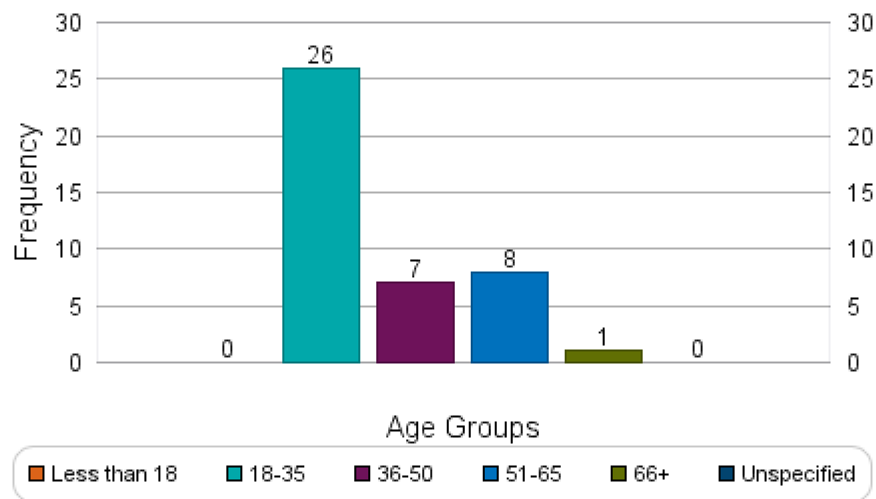

Figure I.15. Bar chart of Visit 5 ethnicity distributions for the 2012 data collection

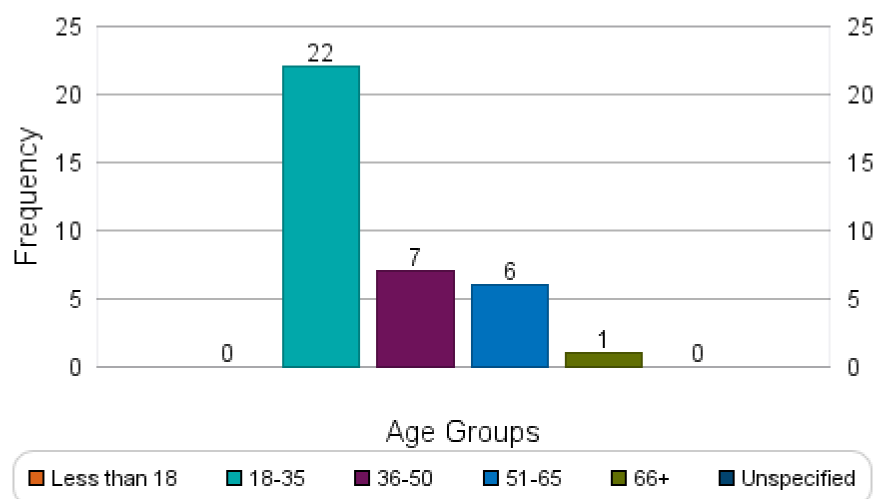

Figure I.16. Bar chart of Visit 6 ethnicity distributions for the 2012 data collection

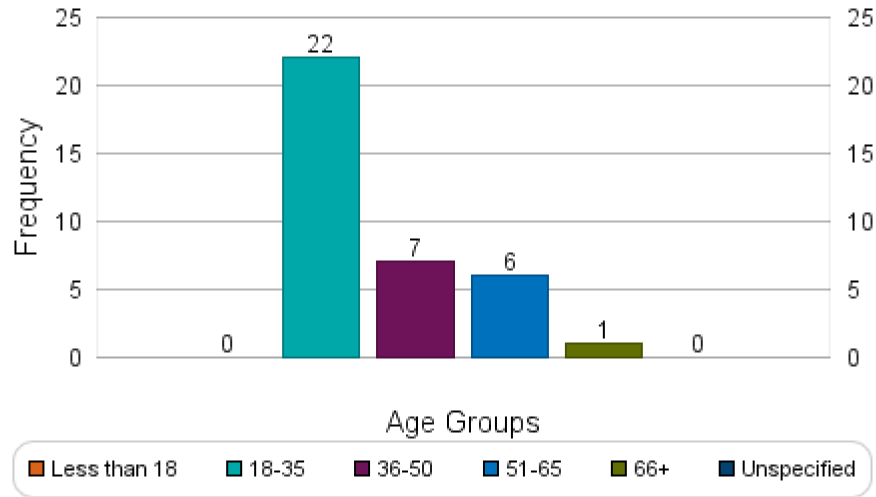

Figure I.17. Bar chart of Visit 7 ethnicity distributions for the 2012 data collection

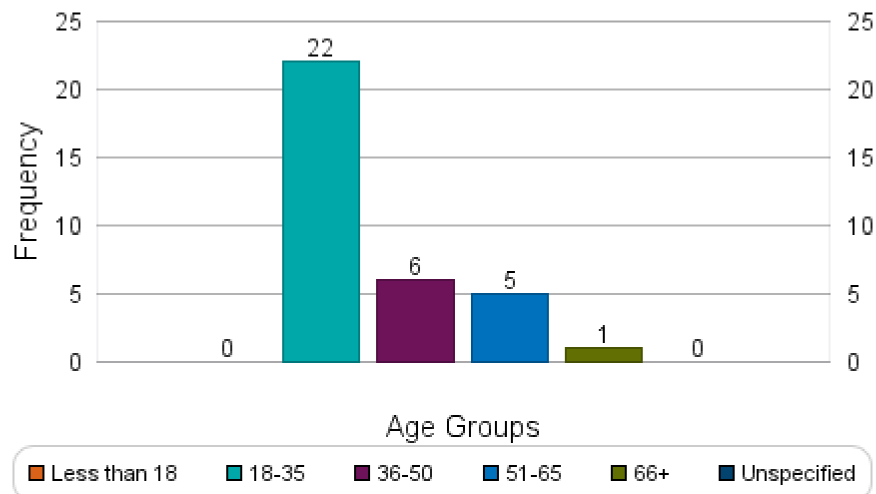

Figure I.18. Bar chart of Visit 8 ethnicity distributions for the 2012 data collection

Appendix J Bar Charts of Subjects per Day for All Visits

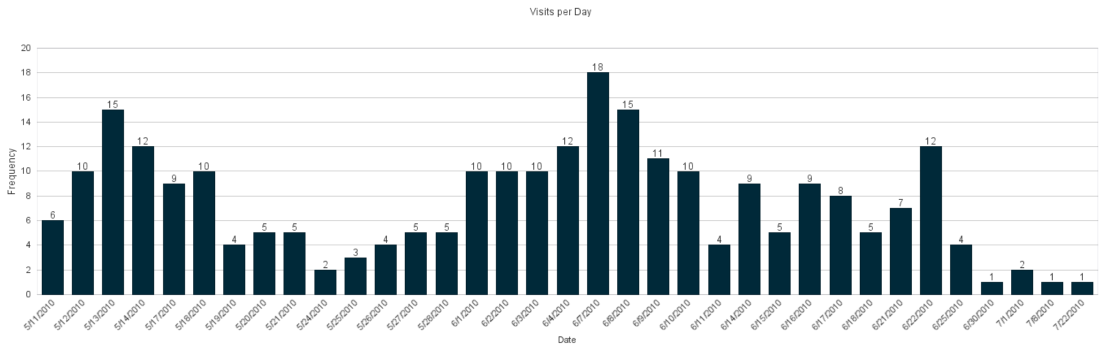

Figure J.1. Bar chart depicting the number of subjects per day for Visit 1 of the 2010 data collection

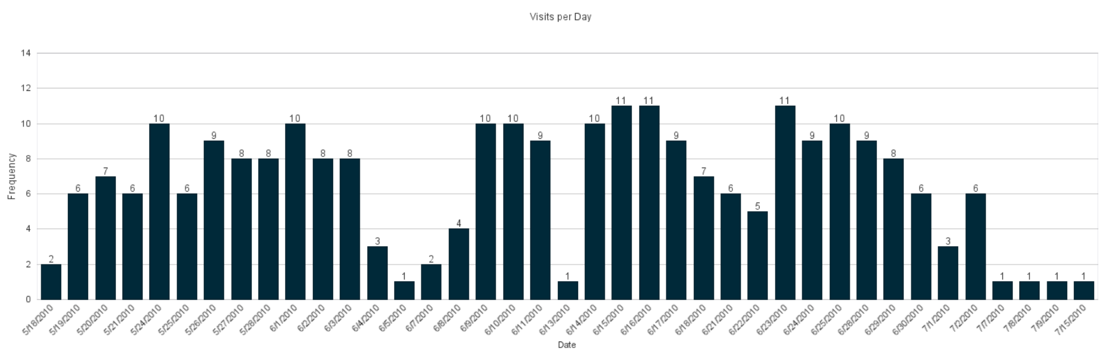

Figure J.2. Bar chart depicting the number of subjects per day for Visit 2 of the 2010 data collection

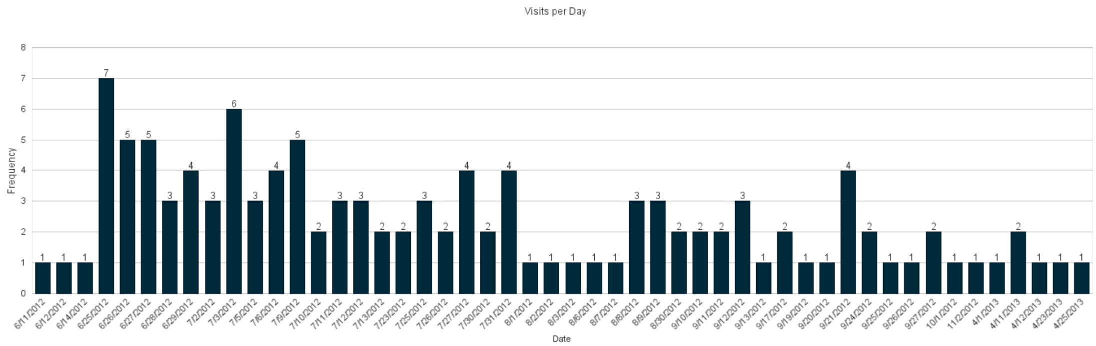

Figure J.3. Bar chart depicting the number of subjects per day for Visit 1 of the 2012 data collection

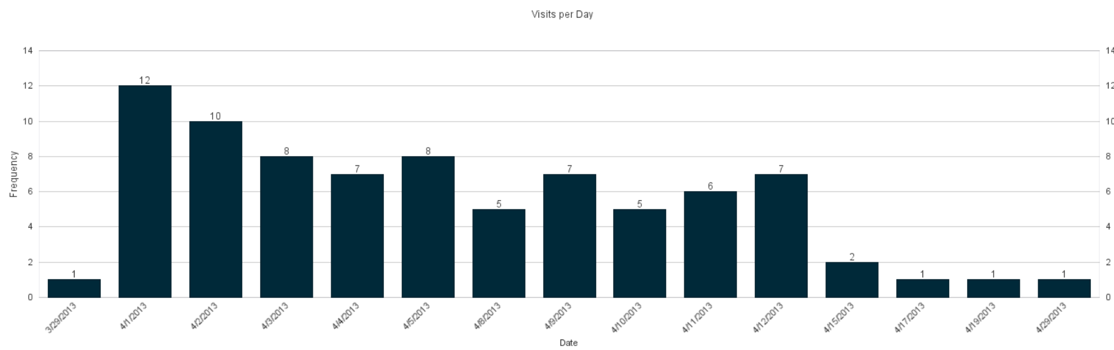

Figure J.4. Bar chart depicting the number of subjects per day for Visit 2 of the 2012 data collection

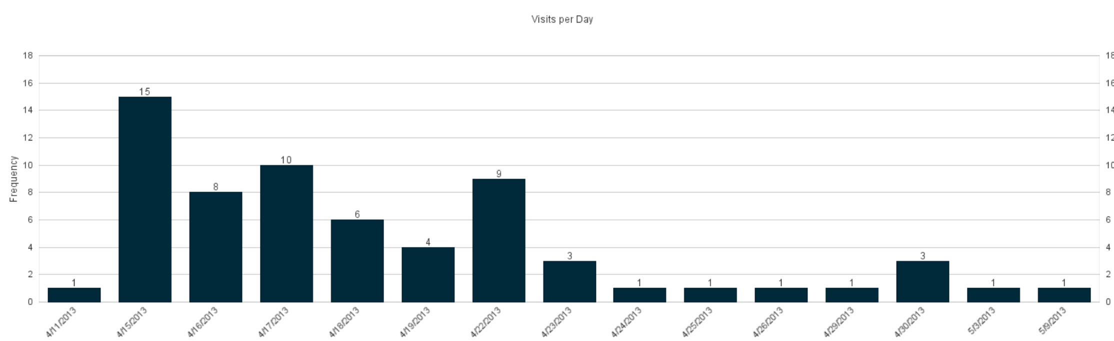

Figure J.5. Bar chart depicting the number of subjects per day for Visit 3 of the 2012 data collection

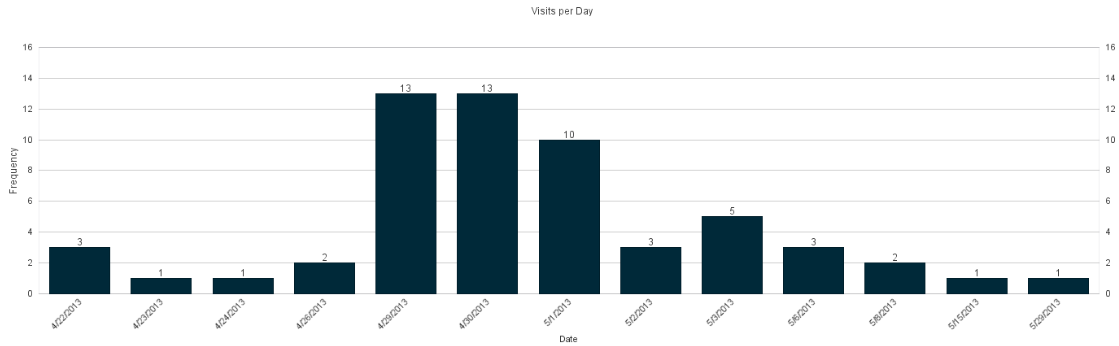

Figure J.6. Bar chart depicting the number of subjects per day for Visit 4 of the 2012 data collection

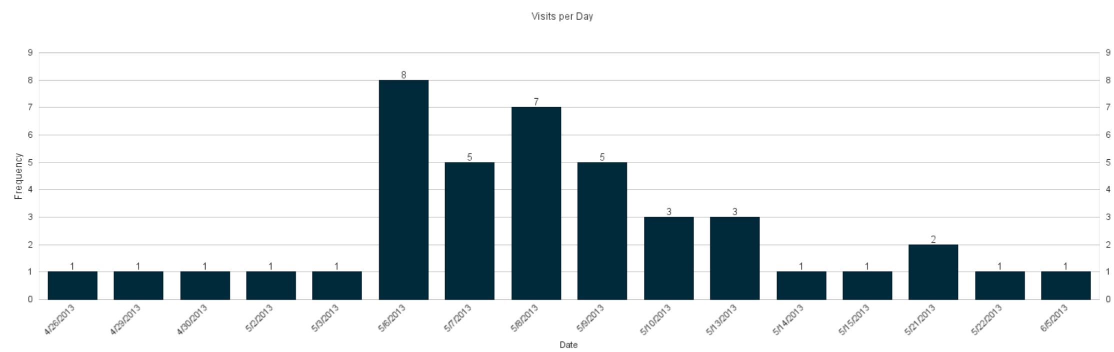

Figure J.7. Bar chart depicting the number of subjects per day for Visit 5 of the 2012 data collection

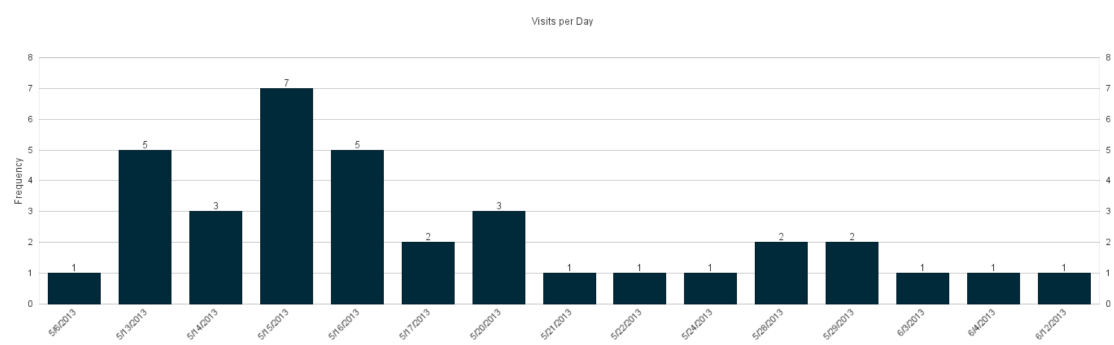

Figure J.8. Bar chart depicting the number of subjects per day for Visit 6 of the 2012 data collection

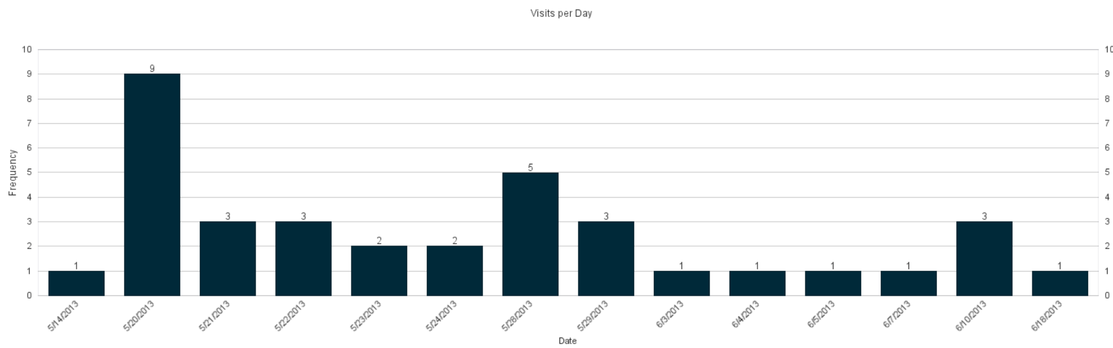

Figure J.9. Bar chart depicting the number of subjects per day for Visit 7 of the 2012 data collection

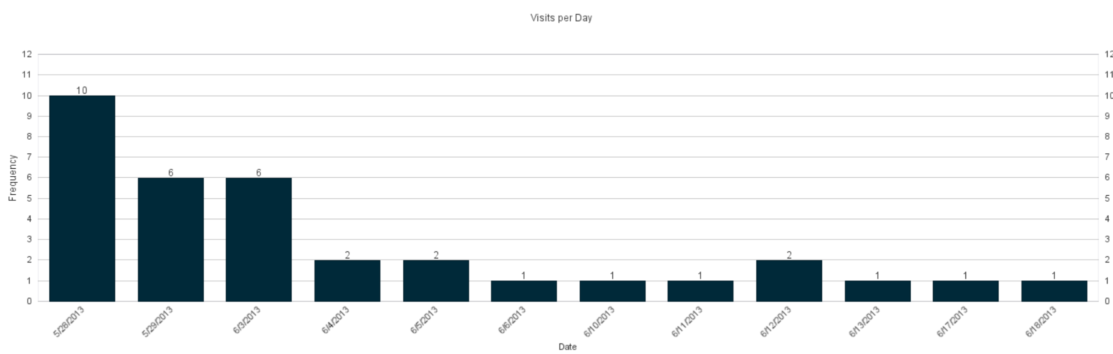

Figure J.10. Bar chart depicting the number of subjects per day for Visit 8 of the 2012 data collection

VITA

VITA

Jacob Hasselgren

Education

2012-2014	M.S.	Technology, Purdue University Thesis: Characterizing Habituation Using the Time-on-task Metric in an Iris Recognition System
2011	B.S.	Computer and Information Technology, Purdue University (3.26/4.00 GPA)

Experience

Corporate

2013-present — Scitor Corporation, Lead Biometric Test Engineer

- Lead the technology sub-team under the Biometrics Team to design a test bed to properly evaluate biometric devices in human subject scenario testing
- Assist in biometric device and equipment procurement

Internships

05/2012-08/2012 — Scitor Corporation, Biometric Qualifications Intern

- Assisted in forwarding the development of a qualification test for iris recognition devices
- Developed test plans to observe human factors in operational environments

06/2011-08/2011 — Fast Enterprises, Implementation Consultant

- Developed and maintained aspects of a tax software suite
- Used Visual Basic/XML/SQL to develop applications

Academic

2012 — Purdue University, Department of Technology, Leadership and Innovation, Graduate Research Assistant

- Progressed individual research pertaining to Master's thesis
- Led a variety of multi-modal biometric data collections

2011-2012 — Purdue University, Department of Technology, Leadership and Innovation, Biometric Data Analyst

- Contributed to assessments of biometric image quality grants

2009-2011 — Purdue University, Krannert School of Management, Student Analyst/Developer

- Maintained the web portal used by Krannert School of Management for class registration
- Created and maintained subsites developed in Sharepoint
- Used C#/XML/SQL/HTML/JAVASCRIPT to develop applications

Conference Preceeding(s)

1. Hasselgren, J., Elliott, S. J., Gue, J., "A Trade-off Between Number of Impressions and the Number of Interaction Attempts", 8th International Conference on Information Technology and Applications (ICITA 2013), Sydney, Australia

Presentations

1. "Evolution of the HBSI Model", contributor to Dr. Stephen Elliott, International Biometric Performance Testing Conference, at the National Institute of Standards and Technology, March 2012

2. "Towards an Iris Device Qualifications Test", contributor to Dr. Dan Potter, Biometrics Consortium, September 2012

3. "Properly Evaluating Biometric Devices for Secure Identity Management Using Human Subject Scenario Testing", speaker, T3 Conference, at Scitor Corporation, March 2014

4. Various biometric presentations internal to Purdue University

Projects

- Develop test protocols for the following organizations:
  - Department of Homeland Security
  - EyeVerify
  - Stanley Black and Decker
  - Scitor Corporation

- Leading the technology sub-team under the Biometrics Team to design a test bed for the Department of Homeland Security (DHS) to properly evaluate biometric devices in human subject scenario testing

- Developed and maintained the test protocol for a multi-modal (face, iris, fingerprint) grant with the Department of Homeland Security (DHS) to examine biometric aging effects on a variety of biometric sensors

- Initiated a grant with Stanley Black and Decker to data mine building access trends

- Contributed as a team member to kick-off a mobile biometric grant with Daon

- Contributed as a team member to a multi-modal (face, iris, fingerprint) grant with the National Institute of Standards and Technology to examine image compression and data transmission effects

Global/International Experience

- International travel experience to Australia and Canada.
- Contributed to projects with international affiliates from the University of Kent (Canterbury), UK.