Human-Biometric Sensor Interaction: Impact of Training on Biometric System and User Performance

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Abstract. Increasingly sophisticated biometric methods are being used for a variety of applications in which accurate authentication of people is necessary. Because all biometric methods require humans to interact with a device of some type, effective implementation requires consideration of human factors issues. One such issue is the training needed to use a particular device appropriately. In this paper, we review human factors issues in general that are associated with biometric devices and focus more specifically on the role of training.

Keywords: biometrics, human-biometric sensor interaction (HBSI), human performance, instruction, training.

1 Introduction

Biometrics is defined as the automated recognition of behavioral and physiological characteristics of individuals [1]. Biometric methods are used to authenticate individuals in a multitude of scenarios, including, but not limited to access control, identity management, and time and attendance. Some biometric technologies include: fingerprint, facial, and iris recognition; hand geometry; vein pattern; and signature dynamics. These biometric technologies may be stand-alone systems, utilized as part of a multifactor authentication system (e.g., combined with physical possessions, such as an identification card, or knowledge, such as a personal identification number), or merged to form a multimodal biometric system (e.g., fingerprint and face) with applications varying widely in scope. Applications for biometrics range from military use, such as base access control and third country nationals identification, to protecting consumer information stored on electronic devices such as laptops, personal digital assistants, and cellular phones.

These deployments have varied in scale and application, and the outcomes of such implementations have varied as well. However, as the biometrics community analyzes lessons learned, one continually discussed area is that of usability and design of biometric devices [2-7]. Questions that arise include: Can current biometric devices provide rapid and accurate responses when needed? Do existing state-of-the-art

M.J. Smith and G. Salvendy (Eds.): Human Interface, Part II, HCII 2009, LNCS 5618, pp. 168–177, 2009.

devices function properly in all applications and environments? Can military personnel capture the biometric sample from a person of interest and not feel endangered? Are consumers satisfied with biometric devices, and do they understand how the devices work?

The goal of research in the area of human-biometric sensor interaction (HBSI) is to address usability issues raised by questions of the above type and investigate them in order to develop the next generation of universally usable biometric systems. Historically, the biometrics community has performed limited work in the area of human-computer interaction (HCI), ergonomics, and usability. To reach the goal of universally usable biometric systems, however, further understanding of the *user* is needed. This understanding includes the exact nature of the physical and cognitive interactions that humans have with the sensor and biometric system, how users can best learn to use biometric technologies successfully, and to what extent users can transfer knowledge regarding use of one biometric system to use of another.

Biometrics are ideally supposed to possess five desirable properties [8]: (1) universality – the biometric property is available on all people; (2) invariance – the features extracted are non-changing; (3) high intra-class variability – the features extracted from one user are distinct from those of all other users; (4) acceptability – the characteristic is suitable for use by everyone; (5) extractability – a sensor can extract the features presented in a repeatable manner. Although commonly described in the literature as the ideal characteristics of a biometric measure, each property must overcome challenges, as the majority of biometrics are challenged to satisfy all of these five categories.

Though early research was concerned mainly with the design, development, and testing of biometric systems and algorithms, recent research has shown that human physical, behavioral, and social factors affect performance of the overall biometric system. This leads to an approach called biometric system ergonomic design (see Fig. 1). The basic idea is that in order for a biometric system to function properly, ergonomic design principles must be incorporated into its design. Factors to consider include the following. The physical environment may alter the biometric characteristics of a person so as to render that person unidentifiable in particular environmental contexts. Determining those physical limits to use a biometric system is important. Users may be uncertain about where, or how, to position themselves to the biometric sensor to get a valid reading, and they may have concerns about using biometric devices for certain applications and in certain contexts. User acceptance of any biometric system is a factor that must be considered in its implementation.

As with any technology with which people are not familiar, instruction and training are necessary when a biometric device is first used. Training is included in biometric system ergonomic design. Training can provide users with knowledge about the properties of the system and with the required steps for their interaction with it. To the extent that biometric devices within a modality have similar features and functions, this training may be generalizable across the set of biometric devices for an entire modality, requiring no additional training when a new device is encountered. To the contrary, if biometric devices within a modality differ in key details regarding their operation, negative transfer may occur in which procedures learned to interact with one device may interfere with use of another device. General principles of training,

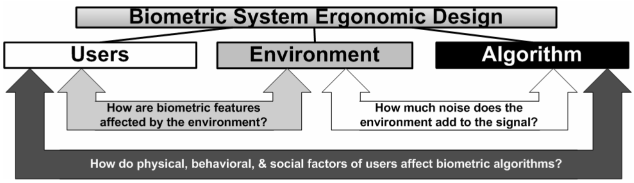

Fig. 1. Issues that affect biometric system performance and the relationship with the HBSI [9]

described later, can provide a basis for studying training within the specific context of use of biometric devices.

If the biometric device is monitored by an assistant, the assistant may instruct the user about the steps in using the device. In most cases, though, an assistant will not be available, in which case training materials must be simple and easy to comprehend. They can consist of a poster that illustrates the steps to be taken by the user, possibly complemented by recorded audio instructions. Feedback is important in learning and performing any perceptual-motor act [10], and it therefore is important that feedback be provided regarding factors such as position of the hand and whether the process was completed successfully. When unsuccessful, the feedback should help enable the user to know what s/he should do to get a successful reading.

2 Biometric System Performance

Traditional approaches to evaluate the performance of a biometric system have been system-level, meaning that evaluators and designers are more interested in system reported error rates, some of which include: Failure to Enroll (FTE) rate, Failure to Acquire (FTA) rate, False Accept Rate (FAR), and False Reject Rate (FRR). Traditional performance evaluations have worked well to evaluate emerging technologies, new biometric modalities, and algorithm revisions. Moreover, since biometrics entered the commercial marketplace, most research has been dedicated to development in three areas: improving performance, increasing throughput, and decreasing the size of the sensor or hardware device. Limited research has focused on ergonomic design and usability issues relating to how users interact and use biometric devices. Furthermore, limited research has examined human performance, specifically how training methods or techniques impact the HBSI and biometric performance.

2.1 Development of the Human-Biometric Sensor Interaction

Any interaction of a human with a biometric sensor requires a series of steps. For example, human interaction with a biometric device that captures the fingerprint of a single finger will typically include the following [11]: (1) visually sight a prompt on a display terminal that prompts the user to place a finger on the fingerprint reader; (2) visually sight the fingerprint reader; (3) move a hand towards the fingerprint reader until it is in close proximity; (4) rotate the hand until the palm side is down; (5) extend a finger until it fits over the fingerprint reader; (6) visually sight the display terminal for confirmation that the fingerprint read was successful. Because several steps are involved in this interaction, task completion time may be long, errors of various types may occur, and, if the problems are very great, user resistance to using the device will increase (see [12] for more extended discussion of these factors). Errors can involve performing the steps out of order, failing to position the finger properly on the fingerprint sensor, failing to keep finger still for long enough to allow the fingerprint to be read, and so on.

Seminal research and publication in the area of usability and accessibility, which was concerned with biometric system ergonomic design, were pioneered by the User Research Group at National Cash Register (NCR) [4, 13]. The United Kingdom Home Office Identity and Passport Service has also published reports based on their biometric trials and implementations which discuss biometric usability and ergonomic design [14]. Maple and Norrington [6] have reported on one particular trial of the United Kingdom's Passport Service Trial Program and its usability, and found issues with each of the three evaluated biometric systems: fingerprint, face, and iris recognition systems. More recently, work in this area has focused on:

- Creating an evaluation method for biometrics that examines biometric performance and usability [15, 16],
- Determining "optimal" device heights for hand geometry [17] and fingerprint recognition [18],
- Usability studies involving a ten print fingerprint capture device [19] and comparison between swipe and large area fingerprint sensors [20], and
- Impact of demography on biometric sample quality and performance [21-23].

Research in the area of biometric system ergonomic design has been called the Human-Biometric Sensor Interaction, or HBSI and is shown in Fig. 2. The model shows how the different areas of research and principles of the different fields of ergonomics [26], usability [27], and biometrics [28] converge in the overlapping HBSI area.

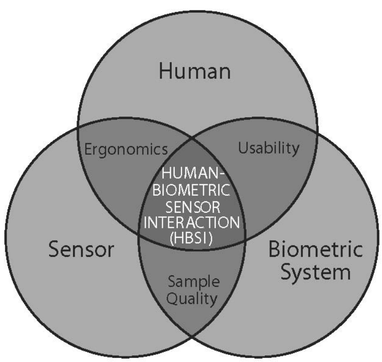

Fig. 2. The Human-Biometric Sensor Interaction Model [9, 15, 16, 21, 24]

2.2 The Human-Biometric Sensor Interaction

The human and sensor components of the HBSI model are similar to Tayyari and Smith's human-machine interaction model [26]. Much like the traditional model, the human and biometric sensor components look to achieve the optimal relation between humans and a biometric sensor in a particular environment. The overlap of these two sections is best summarized by ergonomics, with the goal of adapting the sensor so the presentation of a user's biometric traits to the sensor is more natural to the user.

The human and biometric system components of the HBSI model are arranged in the model to accommodate the way biometric sensors, software, and implementations occur and are presented to users. A biometric sensor must not only be designed so that a user can interact with it in a repeatable fashion, but the sensor(s), software, and the way the entire "system" is packaged must be usable. According to ISO 9241-11 [27] usability is comprised of three factors: effectiveness, efficiency, and satisfaction. Each of the three metrics is distinct and important to understand for products to balance between the three. First, biometric systems must be effective, meaning users are able to complete the desired tasks without too much effort. Second, biometric systems must be efficient, meaning users must be able to accomplish the tasks easily and in a timely manner. Third, users must like, or be satisfied, with the biometric system, or they will discontinue use and find alternative methods to accomplish the task.

As mentioned in the previous two sections, users need to be able to interact with a sensor in a consistent manner over time, and users must find the entire biometric system usable. To enable this to occur, the third relationship of the HBSI conceptual model emerges – the sensor-biometric system, whose key metric is sample quality. Sample quality is the link between these two components because the image or sample acquired by the biometric sensor must contain the characteristics or features needed by the biometric system to enroll or match a user in the biometric system. It is well documented in the literature that sample quality affects the biometric matching algorithm. Yao, Pankanti, and Haas [29] stated that "in a deployed system, the poor acquisition of samples perhaps constitutes the single most important reason for high false reject/accept rates." So, not only does the human-sensor relationship need to be functional and the human-biometric system need to be usable, the sensor-biometric system needs to be functional. An efficient sensor-biometric system only occurs if the sensor can capture and pass usable features to the biometric matching algorithm.

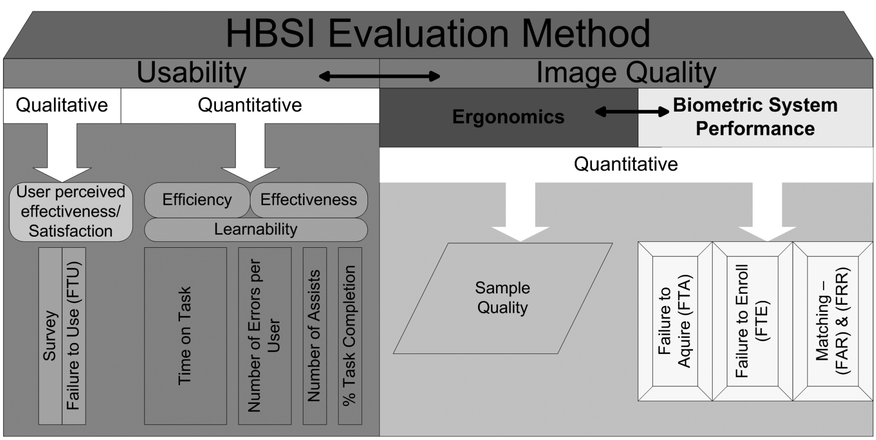

Fig. 3. The HBSI Evaluation Method [15, 16, 24]

To evaluate the model, the overlap of the different components in Fig. 2 has been expanded to reveal the HBSI Evaluation Method (Fig. 3), which addresses how each area of overlap can be measured. Since the conceptual model is derived from different fields, each component (usability, ergonomics, and biometrics) produces a unique output. The authors acknowledge that the metrics used in the HBSI Evaluation Method may produce a trade-off between performance and usability.

3 Training and Instruction

An important component for use of biometric devices is training. Users need to be trained how to use the various devices appropriately in order to optimize the biometric system performance. Yet, relatively little work has been done on training to use biometric devices. In addition to concern about training a person to use a particular device within a specific environment, it is also important that the training transfer to different environments in which the same device is used and, more importantly, to different devices of the same general type.

3.1 Principles of Training and Transfer

Though research on training and transfer with biometric devices is sparse, research in cognitive psychology has established many broadly applicable principles of training and transfer for both knowledge and skills [30]. Many of these theoretical principles should be applicable to the domain of biometrics. Their application will help determine the best way to train people to use biometric devices and predict how well this training can transfer to new/alternative devices. We describe below various training principles [31] that could be applicable to developing effective training practices for use of biometric devices.

One generally accepted principle is the power law of practice. According to this principle, the time to complete a task decreases as a function of the number of times it is performed. This means that having people perform the same task multiple times may be an effective form of training. A related principle is that of deliberate practice: Practice is most beneficial when it is highly motivated and focused. Deliberate practice has been shown to be necessary for skill acquisition in a variety of domains. The principle of depth of processing emphasizes that training which requires deep and elaborate processing, creating distinctive encodings, enhances durability of knowledge and skills.

According to the principle of contextual reinstatement, performance of a task at a later time (the test) is improved by training that matches the test conditions as closely as possible. Closely related to this principle is that of procedural vs. declarative training. Procedural training is more durable than declarative training, whereas declarative training leads to better generalization. With regard to instance- vs. rule-based training, instance-based strategies lead to more efficient performance in simple tasks, whereas rule-based strategies lead to more efficient performance in more complex tasks. Also, rules tend to be more durably represented in memory than are instances. People will tend to remember rules better than specific instances.

Knowledge seeding is sometimes beneficial for training. When tasks require having a certain type of quantitative knowledge, providing a small number of examples is often sufficient knowledge to encompass an entire domain. The principle of spacing of practice is that knowledge is retained for longer periods of time when training sessions are spaced in time. The power law of forgetting is that performance decreases as a power function of the time since training [32]. One of the more intriguing findings in recent years is that testing impedes forgetting: Testing after initial presentation of material slows forgetting [33]. In the area of information security, this principle has been found to hold for memory of several passwords used to access different e-commerce sites [34]. The final principle is generalization depends on similarity. The gain in performance on one task as a consequence of training on a different task is an exponentially decaying function of the similarity between the two tasks [35]. Thus, transfer can be expected to occur to the extent that the transfer task is similar to the task used at training.

3.2 Training and Instruction Research in Biometrics

Not much research has been conducted investigating the impact of training on biometric and usability performance measures. The most extensive study was one conducted by researchers at NIST to evaluate the time to acquire a 10-print slap fingerprint image using three different instruction methods [19]. Participants were told to make a right slap, left slap, and simultaneous thumb prints. One of three instructional techniques was used for each participant: a poster illustrating the steps; verbal instructions spoken by the test administrator; a soundless video demonstrating the procedure. Participants who received the poster instructions made more errors than those who received the verbal or video instructions. Moreover, only 56% of the participants in the poster group completed the fingerprinting process, a smaller percentage than in the other instruction groups, and those who did complete the process took longer to do so than did the participants instructed by the other methods. A limitation of the study is that participants instructed by poster were allowed to self-determine the duration for which they examined the poster, whereas participants in verbal and video conditions were required to engage in the training on average approximately 50 s. In fact, the median time spent examining the poster was approximately half the duration of the other instructional conditions. Thus, the poorer performance with the poster instructions may be a consequence of not studying the poster for a sufficiently long duration.

We currently are conducting an experiment to evaluate this possibility by allowing one group of participants to self-determine how long to examine the poster, as in [19], but having another group examine the poster for a fixed period of 50 s, a duration comparable to that for the other training methods in [19]. Preliminary results agree with the findings of [19] in suggesting that the poster alone is not a particularly effective instruction method, even when participants are required to view the poster for a longer time than they do when allowed to self-terminate.

Kukula, Gresock, Elliott, and Dunning [36] examined the influence of type and amount of user training on interaction with a hand geometry biometric device. Because hand geometry depends on orientation of the user's hand, most hand geometry devices have pins with respect to which the user's hand must be positioned for correct alignment. Training is perhaps even more important for hand geometry devices than for fingerprint reasons because it needs to convey how users should interact with the alignment pins. Four groups of participants received initial instructions and demonstrations of using a hand geometry device. They then received different amounts of practice with the device one day per week in some weeks of a six-week training period. In the seventh week, all participants were required to achieve a criterion of three consecutive successful readings with the device at a set performance level (threshold set to 30). The control group performed only the criterion task in the last session. The group that received the most practice performed the task to the same criterion of three successful readings in four of the six weeks prior to the final test. This group showed continued improvement in performance over the period and performed the best of any group in the final session. This result is consistent with the power law of practice, for which performance improves with continued practice. Of interest were third and fourth groups, each of which were required to perform only three successful readings prior to the final session, but differed in when those were done. One group performed all three readings in the first session (week 1), whereas the other group had the readings spread out over three different sessions, each separated by a week. The former group did not perform any better in the test session than in week 1 and was the worst of the three practice groups in the week 7 test. In contrast, the latter group showed a benefit of the prior practice. This outcome is consistent with the spacing of practice principle, though differences in retention interval preclude a clear attribution of the difference to that factor.

The point of these studies is that various aspects of training, including instructional materials and practice schedules, influence users' performance with biometric devices. This work is only a start of the research that needs to be done to establish the most effective ways to teach people to use various biometric devices.

4 Summary and Conclusions

In this paper, we connect cognitive ergonomics to biometrics because prior work in the area of biometric system ergonomic design has tended to consider mainly physical ergonomics and usability. We focused on principles of training and transfer that need to be applied to and evaluated in biometrics to ensure that users know how to interact with biometric devices. Cognitive ergonomics has tended to be left out of biometric considerations, as in the case of the HBSI Evaluation Method (Fig. 3). Thus, future work needs to be done to further examine and revise the HBSI Evaluation Method to include assessment of training and transfer, as well as other cognitive factors that have been shown to affect performance.

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