ELECTRONIC PRAYER RUG: DESIGN AND EVALUATION

By

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A THESIS SUBMITTED IN CONFORMITY WITH THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

GRADUATE DEPARTMENT OF COMPUTER SCIENCE UNIVERSITY OF TORONTO

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Abstract

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degree of Doctor of Philosophy

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For more than a thousand years, the prayer rug has been used by Muslims, around the
world, to conduct the five daily prayer rituals. The rug has undergone very little
modification since it was first used – mainly aesthetics in the form of adding motifs and
patterns. This dissertation constitutes the first major enhancement to the prayer rug: an
electronic version that neither compromises the traditional form nor the simple
interaction associated with the passive device. This modern version of the prayer rug
enhances the spiritual experience of Muslims during prayer. The electronic version also
supports the display of Quran verses – enabling Muslims, for the first time, to read un-
memorized parts of the Quran during prayer.

This dissertation makes a number of key contributions; first, a study of the challenges
facing Muslims in fulfilling prayer requirements. Second, the design and implementation
of the electronic prayer rug – the first of a kind device – to support Muslims during
prayer rituals. Third contribution is using Electroencephalography to evaluate the impact
of a newly designed digital device (electronic prayer rug) to support religious rituals – the
first of a kind study. Fourth, conducting a four month longitudinal study to evaluate the
long term impact of a newly designed digital device (electronic prayer rug) to support
religious rituals – also the first of a kind study. The fifth contribution is an HCI-centered reviews and taxonomies of rituals and related tools, from several religions. These studies are the first to be performed within the area of digital tools for religious rituals.
Acknowledgments

Whatever good, happens to thee, is from God; whatever evil (bad) happens to thee, is from thy soul (Quran 4:79).

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For any errors or inadequacies that may remain in this work, of course, the responsibility is entirely my own.
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Chapter 1

Introduction

1.1 Motivation

This PhD dissertation is about the conception, design, development and evaluation of an electronic prayer rug for Muslims. Two questions I have been repeatedly asked while working on this thesis is: why care? and; why focus only on Islam? After all, religion – with the exception of tragic events – seems to have less impact on people’s life in the twenty-first century. The answer to the first question is three fold; first, the claim that religion is becoming less important in people’s life is inaccurate. Billions of people worldwide are adherents of some form of religion. Although exact figures are not available, it has been estimated that 80% of the world’s population practice a religion (Religious populations, 2007). It is no exaggeration to claim that one of the most common and frequently performed tasks is some form of religious ritual, performed either daily, weekly, or on special occasions. Second, many people believe that religion is an important part of their life. For example, in the US, 72% pray every day (Gallup Organization, 1993), and 90% of adults contend that their religious faith is important in their life (Barna Group, 2005).

The third reason behind designing for religious rituals is that research has uncovered a strong correlation between practicing a religion and positive outcomes for the user and for society. There have been several important studies that have shown this outcome.

Correlation between Religiosity and Positive Outcomes for the Individual
Kizmaz (1998) conducted studies on 500 practicing Turkish Muslims and found that 40% of those who performed prayer reported feeling happiness and comfort after the practice and 26% felt relieved. Similar findings have been reported by studies focused on practicing Christians. Welford (1947) noted that believers consider prayer an important tool to overcome frustration while Loveland (1968) highlighted prayer’s role in coping with loss of loved ones.

Research also showed that practicing a religious faith could improve the health condition of patients – regardless of the alignment type. Yucel (2007; 2010) conducted a study of 60 adult Muslim patients from various ethnic backgrounds in a Harvard affiliated hospital. Patients completed questionnaires that were used to assess the respondents’ psychological and emotional well-being. Vital sign recordings and self-report surveys were used before and after prayer sessions to measure effects of Islamic prayer. A non-religious text served as a control. Results support the hypothesis of the positive effects of prayer1.

Similar findings were also reported by studies focusing on Christian patients. A study conducted by Ai et al. (Ai, Bolling, & Peterson, 2000) showed that using prayer to cope with coronary artery bypass surgery was positively correlated with better postoperative emotional health. Koenig (1999) suggested that the immune systems status is correlated with frequency of attending church services. In a review of over 50 studies which investigated the relationship between religion and health, and which covered almost all types of medical problems, found that the majority of these studies provided some evidence of a significant statistical association between religious activity and better

---

1 Yucel’s work is not the only research that showed such effect. Rahman (1987), Habib (1995), and Athar (1996) have all reached to a similar conclusion.
mental or physical health (Larson & Larson, 2003).

The benefits of practicing a religious faith also extend to the senior population. Oman and Read (1998) found that older attendee of Christian services had lower mortality rates than those who did not. A longitudinal study of approximately 3000 senior US citizens found that frequent religious attendees were significantly less likely than infrequent attendees to be physically disabled 12 years later, a finding that persisted after controlling for health practices, social ties, and indicators of well-being (Idler & Kasl, 1997).

**Correlation between Religiosity and Positive Outcomes for Society**

Studies have shown positive relationship between religiosity and positive behaviour and attitudes. For example, a number of surveys have uncovered an association between religious faith and altruism (e.g. Ellison, 1992; Benson, Kedem, & Cohen, 2001). Several criminological studies have established the existence of an inverse relationship between religion and crime (e.g. Elifson, Petersen, & Hadaway, 1983; Doris, 2007). Indeed, a review of more than 50 studies on religion and crime concluded that “religious behaviors and beliefs exert a moderate deterrent effect on individuals’ criminal behavior” (Baier, 2001:5).

Despite the evidence of the popularity of religious rituals, the benefits, and the absence of technical obstacles, little has been done in the field of Human Computer Interaction (HCI) to design and evaluate user interfaces to support such tasks. This reluctance within the HCI community can be attributed to a number of reasons, including:

**Fallacy of Numbers**

It is more common to develop user interfaces and tools to enhance the productivity of individuals, due to the anticipated direct economic benefits. The HCI community has
been less concerned – Picard’s work (Picard, 1995) on affective computing being an exception – about how satisfied the user is with psychological well-being.

**Ambiguity of Evaluation**

Psychology researchers have only recently started studying religious practices, henceforth, the accumulated body of knowledge that HCI researchers could use in evaluating an interface for religious rituals is still fairly limited.

**Lack of Interest in Religion**

According to Ecklund and Scheitle (2007) 62% of academics and scientists do not believe in the existence of a creator\(^2\). Consequently, designing for a religious ritual might not necessarily be an activity that interests this majority of researchers.

**Topic’s Sensitivity**

The small number of HCI publications related to sex, politics, or religion, shows that the community has generally been avoiding these three topics due to the potential sensitivity. Going back to the first question; why care about designing for a religious ritual; I am a practicing Muslim and I believe that technology has a place in supporting Islamic religious rituals for practicing Muslims who are unable to accomplish them. Also, regardless of the potential benefits, religious practice is important to people who practice that religion. Developing technologies to support those individuals to continue to practice throughout their lives regardless of ability or disability is important to me as well as a scientific and technical challenge. Answering the second question – why Islam; as I am a practicing Muslim, it seemed to be an excellent fit for me. I believe that designing for a religious ritual requires the designer to see through the physical movements, and the used

\(^2\) Although Ecklund and Scheitle (2007) work was focused on US scientists, the findings are applicable to Canada.
phrases to the underlying meanings of the ritual. Those practicing a religion can be the best suited to understand such subtleties and utilize them in interface design. In this thesis, I have risen to the challenge of designing an interface for religious ritual. Although, my focus is on Islamic prayer, rituals from other religions and the devices that were created to support them are also presented in the thesis. Several surveys are presented with the hope that they will aid HCI researchers working in this new area.

1.2 Research Questions

This PhD dissertation covers three related topics: Muslim prayer challenges and requirements, designing an interactive digital system and interface for supporting Muslim prayer, and evaluating such system to ensure that it does not negatively affect the quality of prayer. Following is a description of the main research questions;

Question 1: What Obstacles Face a Muslim while Trying to Fulfill the Daily Prayer Obligations?

Muslim prayer is a demanding task; performed five times a day, during shifting time intervals, and requires the memorization of Quran verses as well as prayer rules. To answer this question, information gathering interviews were conducted with practicing Muslims to learn about challenges faced and any strategies adopted to help with the execution of prayer. A second interview was conducted with a religious scholar to learn about the practice, relevant rulings and opportunities for technology assistance.

Question 2: What is the Most Effective Religiously-Acceptable Design for Supporting Muslim Prayer?
To answer this question, the research was started by conducting a review of existing tools for religious practices. The motivation behind this activity was to understand the space of religious tools, in terms of their typical usage, acceptance by laity, utility of different tools, and the impact of religious rituals and rulings on tool design and development. Next, an iterative design process was followed to develop a prayer assisting system. During that process, several questions arose: What is the best system form that is both religiously acceptable and also user-friendly? Which physical characteristics – material, color, and so forth – are most suitable? What is the best way to interact with such a system? What features would participants desire? In case of error, would form of communication between the system and user is acceptable?

*Question 3: What is the Effect of Using a Digital System during Prayer on User Performance?*

While tools for secular tasks are evaluated for efficiency and effectiveness, religious tools cannot be judged by these criteria. To answer this question, physiological measures were considered as a viable means for understanding user state during prayer and after establishing that, it was used to evaluate performance while using the new system. In addition, a longitudinal study was performed to investigate the long term impact.

### 1.3 Statement of Thesis

In this dissertation, I present the electronic prayer rug, a portable digital device for supporting Islamic prayer rituals. Through an integrated, inter-disciplinary approach that combines research in Neurophysiology and HCI, I attempt to demonstrate that by using the electronic prayer rug, user’s spiritual experience could be improved.
1.4 Contributions

This dissertation’s contributions are a reflection of three inter-dependent directions; supporting Islamic prayer rituals through a digital interface, investigating appropriate means to evaluate digital devices used in religious rituals, and documenting and classifying the space of religious rituals and tools. The contributions are:

**A study of the challenges facing Muslims while fulfilling prayer requirements.** I have identified a set of requirements drawn from interviews with practicing Muslims and a religious scholar.

**The design of an electronic prayer rug.** Several prototypes were developed and evaluated according to an iterative design process. The final outcome is a device – the first in its category – that I have provided some evidence to show that it can enhance the spiritual experience of Muslims.

**An assessment of the effect of introducing a digital device into a religious ritual.** I have demonstrated that neurophysiologic indicators can be used to quantify the user’s spiritual experience. Newly designed digital devices and interfaces could follow the same approach in evaluation.

**An evaluation of the long term impact of using a digital device in a religious ritual using flow theory.** I have demonstrated that flow theory could be used to evaluate the long term impact of using a digital device in a religious ritual.

**A study of religious rituals and Tools from an HCI perspective.** I have conducted two surveys of the different types of religious rituals and tools, and placed them in taxonomies that will enable other HCI researchers to better contextualize works in this new area.
1.5  Structure of the Dissertation

1.5.1 Outline of the Dissertation

The dissertation is structured as follows:

**Chapter 2: Interviews with Practicing Muslims.** Prior to the design of the electronic prayer rug, a series of interviews were conducted with practicing Muslims to investigate challenges related to performing prayer. Next, a religious scholar was interviewed to clarify the religious rulings pertaining prayer. The interviews are summarized in chapter 2 and a list of requirements and design challenges are identified.

**Chapter 3: Survey of Religious Rituals and Tools.** The space of religious rituals and supporting tools is new to HCI. This chapter presents taxonomies of both topics from an HCI perspective. A detailed overview of Islamic prayer, relevance and requirements is also presented.

**Chapter 4: Design Evolution of the Electronic Prayer Rug.** Chapter 4 is dedicated to describing the design iterations of the electronic prayer rug.

**Chapter 5: Evaluation of the Electronic Prayer Rug.** Chapter 5 is focused on reporting the method and results of neuro-physiological and subjective studies conducted to evaluate the user performance while praying using the electronic prayer rug.

**Chapter 6: Conclusions.** The final chapter contains a summary of the research, implications for future research, limitations of the experiments, contributions, as well as a presentation of future research directions stemming from this work.
1.5.2 Outline of the Surveyed Related Work

Due to multidisciplinary nature of this research, related works from different disciplines are reviewed in the relevant chapter, as follows:

**Chapter 3: Survey of Religious Tools and Rituals.** Modern digital tools and interfaces are reviewed and discussed while presenting taxonomies of rituals and tools.

**Chapter 4: Design Evolution of the Electronic Prayer Rug.** This chapter contains a review of enabling methods and techniques for detecting user posture which is a requirement for supporting Islamic prayer.

**Chapter 5: Evaluation of the Electronic Prayer Rug.** This chapter contains reviews of; the use of physiological measurements techniques in HCI, flow theory, Electroencephalograph, studies on the cognitive effect of religious rituals, and studies on Islamic prayer.
Chapter 2

Interviews with Practicing Muslims

This research began with the author noticing that there was a common desire among Muslims to enhance the quality of their prayer. To verify this observation, interviews were conducted with six Muslims about their daily prayer practices. A religious expert was also interviewed to determine the constraints and rules of prayer. The following section provides background information about Islamic prayer.

2.1 Islamic Prayer

An adult Muslim is required to perform prayer, called Salah, five times a day. Each prayer has a time interval, which are measured according to the movement of the sun; near dawn, just after noon, in the afternoon, just after sunset and around nightfall. Salah consists of prescribed and ordered steps as shown in Figure 2.1. The activity consists of several steps and gestures performed in place. The activity begins with a saluting gesture (Figure 2.1a) accompanied with the statement "God is the Greatest", followed by a standing posture called qayam (Figure 2.1b), during which the adherent must recite from memory both the first chapter (Figure 2.2a) from the Quran - Muslim doctrine - followed by at least three verses from any other Quran chapter. The Quran consists of 30 parts of roughly equal divisions comprising 114 chapters and 6346 verses. Muslims need to memorize the first chapter and any other three verses as a minimum to be able to perform Salah. After finishing the recitation from memory, the adherent must bow, and repeat the phrase "Glory to my Lord the Exalted" three times while bowing (Figure 2.1c), then stand...
and say "God listens to him who praises Him" (Figure 2.1d), next prostrate twice in a posture called sajdah, (Figures 2.1e and 2.1g). While the forehead is resting on the ground, a Muslim repeats "Oh Glod glory be to you, the most high" three times followed by personal free-form supplication to God. The two prostration are separated by a sitting posture (Figure 2.1f) in which the supplication "Oh God, forgive me, have mercy on me, increase my overall wealth, and cure me", is said at least once. Finally, the Salah is concluded by the postures illustrated in Figure 2.1h to Figure 2.1j during which the adherent recites the tahayat which are a set of supplication phrases (Figure 2.2b), followed by turning towards right and saying "Peace and mercy of God be on you" and turning towards the left and repeating the same sentence. The postures illustrated in Figures 2.1b to Figure 2.1g are collectively called a rakaa and are repeated two, three or four times depending on which daily Salah is being performed. During the Salah, any additional movements beside the prescribed steps are forbidden, except in emergency situations, where one can interrupt the Salah. If the adherent commits an unintentional omission or commission error, an apologetic gesture is performed at the end of the Salah by repeating the steps illustrated in Figure 2.1e to Figure 2.1g twice. The tradition teaches

![Salah postures](image)

**Figure 2.1: Salah postures – from (Aydin, 1992).**
that recitation of the Quran should be done silently but in a vocally active way where the Muslims must move her tongue while reciting.

There are three types of errors that could be made during Salah: skill-based, rule-based and knowledge based. Skill-based slips involve replacing sequence of steps with another more common sequence. For example, in the last part of a Salah, at step of Figure 2.1g, the practitioner need to conclude the prayer by performing the steps of Figure 2.1h to Figure 2.1j, but instead automatically stands up to step of Figure 2.1b since standing back up is done more often. This kind of error is common and happens more often in mosques while conducting group prayer. Often those praying behind the prayer leader, Imam, would utter a religious phrase to signify to the Imam that he made a slip. Rule-based errors involve the practitioner getting confused about when to perform which step. For example, in case of a detected error, practitioners often get confused when to perform the apologetic step; whether it is before or after the concluding steps. Knowledge-based mistakes involves being unaware or forgettable about the ruling pertaining the prayer. For example, certain mistakes performed during prayer nullify the prayer; yet, some practitioners assume that all mistakes can be compensated by an apologetic gesture at end
of prayer. For example, at step of Figure 2.1b, the practitioner must recite two chapters from the Quran, the first chapter to be recited is the first chapter in the Quran scripture, and the second is any other Chapter, or part of chapter, from the Quran provided it consists of a minimum of three verses. A practitioner who does not know the count of the verses being recited will do a violation that nullifies the prayer.

To perform valid Salah, Muslims must be in a state of ritual purity, which is achieved by ritual ablution according to prescribed procedures. Since the place of prayer must be clean for a valid Salah, Muslims often use a piece of fabric, often called the prayer rug, to perform the prayer on.

2.2 Interviews with Practicing Muslims

Anonymous surveys and personal interviews are two tools commonly used to illicit user input. Interviews were preferred since the dialog in an interview can potentially generate far more valuable data than surveys. Selecting participants for interviews on ritual performance and prayer habits turned to be a challenging task because it is considered a stigma to not be performing Salah within the specified times or without concentration. Consequently, Muslims often feel embarrassed about disclosing their level of prayer observance. The author decided to interview relatives and family friends, close and distant, who were known to be committed to the practice to avoid false positives.

Six participants were selected, three females and three males ($M$ (age) = 64.6 yrs, $SD = 3.9$). Table 2.1 lists the age, gender and number of Quran pages memorized for each interviewee. Using Skype™, web-based interviews were conducted with the participants using a narrative interview methodology (see Appendix A for a list of the pre-determined
Table 2.1: Interviewees’ age, gender and number of Quran pages memorized

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Gender</th>
<th>Quran Pages Memorized</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>70</td>
<td>F</td>
<td>3</td>
</tr>
<tr>
<td>P2</td>
<td>69</td>
<td>F</td>
<td>5</td>
</tr>
<tr>
<td>P3</td>
<td>63</td>
<td>F</td>
<td>1</td>
</tr>
<tr>
<td>P4</td>
<td>61</td>
<td>M</td>
<td>6</td>
</tr>
<tr>
<td>P5</td>
<td>64</td>
<td>M</td>
<td>7</td>
</tr>
<tr>
<td>P6</td>
<td>61</td>
<td>M</td>
<td>16</td>
</tr>
</tbody>
</table>

questions used during the interviews). The purpose of the interviews was to get the participants to speak as specifically as possible about their own experience and to clarify what they meant along the way. This was done to furnish a condition for understanding the experience and related meanings which emerge in the dialogue (Mishler, 1986a; 1986b). Participants were encouraged to express their experiences freely and continuously. The interviews began with a question asking the participants to narrate their daily prayer ritual and the issues related to it: “I want to ask you to tell me how do you engage in performing the daily prayer rituals. The best way to do this would be for you to start from the early morning, and then tell all the things that are related to prayer, one after the other until the day is concluded. You can take your time in doing this, and also give details, because for me everything is of interest that is important for you.” Clarifying and encouraging questions were used, for example, “Can you explain a little more what you mean?” and “can you give me an example?” The time of interviews were pre-arranged and the participants were informed that they could withdraw at any time. No voice recording was done. It was felt that a formal recording might have impacted on the existing trust between interviewees and interviewer. The interviews ranged from about 40 to 60 minutes in length. Colaizzi’s (1978) six steps methodological interpretation approach was used to guide the study and the procedural steps. Each participant’s narrative was transcribed verbatim by the author using hand writing and analyzed for
significant statements and meanings. Phrases were extracted, and meanings were formulated and organized into themes. These themes were then used to provide a summary of the narration. Next, the summary was read back to each participant in order to check for validity. The following six challenges were uncovered;

**Challenge 1: Recalling Prayer Times**

All the participants reported that they found it difficult to perform the prayer in the designated time interval. The more senior participants, being aware of the effect of aging on their memory skills, were coping by inventing creative strategies to recall performing the task. P1, P2 and P5 reported that they place the prayer rug in a visible place in their home as a reminder to perform prayer. P1 reported “I put it beside TV, so if I forgot to pray - seeing it will remind me”. P5 reported “I put it on the back of my couch so it is always in front of me”. P3, whose hearing had declined significantly in the last few years, bought an alarm with Muslim Call to Prayer which plays an Islamic audio recording whenever the beginning of a prayer time arrives. P3 places the alarm beside her bed but sometimes does not hear it when she is watching TV in the living room “I have to remember to get the alarm from inside and put it beside me”. P6 mentioned that he often forgets to perform the night prayer due to irregular sleeping habits so, he asked his daughter to phone him every night and remind him. P4 reported that “I always have TV on during the day and I only watch those channels that broadcast the Islamic call to prayer so I don’t forget to pray.”

**Challenge 2: Logging Prayer Performance**

Half the participants mentioned that they sometimes find it hard to remember if they prayed or not. Because Islamic prayer times are interval based, the individual can
perform the prayer anytime within the designated interval. For example, the sunset interval lasts an average of 1.5 hours while the noon prayer interval lasts an average of 3 hours. P4’s daughter³ said, “Dad sometimes prays and then after a while he forgets so he prays again.” P2 mentioned, “The best thing is to perform the prayer once you hear the Azan⁴. This way I don’t have to worry later on if I prayed or not.” Hence, the call to prayer becomes a memory aid (which is the original intention behind it – to make Muslims in the neighborhood aware that they should pray). P1 who developed arthritis likes to pray in the sunlight: “I like to perform the noon prayer in a spot in my living room where there is a direct sunlight and then I pray the afternoon prayer in my bedroom because the sun moves there. If I notice the prayer rug is not in the right place, I realize that I forgot to pray.” In this case, the location of the prayer rug is used as a memory cue. Surprisingly, none of the participants reported that they attempt to document, in writing or otherwise, their performance of prayer.

Challenge 3: Performing Prayers Correctly

Muslim religious rituals are highly repetitive. Consequently, the most common source of error is to forget the number of steps or type of gestures already performed, leading to omission or commission errors. Omission errors are made when the user wrongly assumes that a step was performed and misses that step while commission errors are made when the user wrongly assumes that a step was not performed and performs it again. From a religious point of view, these kinds of errors could invalidate the prayer. P4 said, “Many times I am praying and wander away so I lose track of how many steps I made, I go back and do more just in case – then perform the apologetic step at the end.”

³ P4’s daughter participated in the interview since P4’s memory degraded with age.
⁴ Islamic call to prayer.
P5 adopted a similar strategy but he added, “What is worse is that by the time you reach to the last step in the prayer, you don’t know if you should perform an apologetic gesture or not because you forgot if you detected a mistake in the prayer or not – so I do it anyway. Sometimes, after the prayer, I might remember that I didn’t do a mistake in this one – it was the previous prayer to this one that I made a mistake in but I just got confused.” P3 developed a more sophisticated strategy, “I intentionally recite certain verses in the first part of the prayer and recite a second different set of verses in the second part of the prayer and so on. If I get confused how many steps I made, I try to remember which verses I last recited.” Hence, she is establishing a mapping between verses and steps and that mapping is used as a memory aid.

_Challenge 4: Remembering Verses from Scripture_

During prayer, a Muslim is required to recite verses from the Quran from memory and the verses must be recited in the exact way they are written. Holding the scripture in the hands during prayer to read from is not part of Islamic tradition and is discouraged by the religious scholars. The rationale being is that maintaining physical balance while holding a weight and being concerned with turning pages will distract the individual and cause a loss of concentration, hence invalidating the prayer.

Out of the 624 pages of the Quran, P3 only remembered 1 page which she used while praying most of her life, while P6 memorized 16 pages. The remaining participants memorized an average of 5 pages. Although all the participants read the Quran (outside daily prayer) for spiritual and contemplative purposes, they were reluctant to use verses they have not completely memorized during prayer in order to avoid invalidating the activity. As P4 noted “I know more of the Quran than what I use during prayer.
However, I only use those (verses) that I am sure I remember vividly.” When asked if they would like to be able to read more verses from the Quran during prayer, all the participants expressed great interest and desire to do so⁵.

Challenge 5: Customizing Prayer

Participants were interested in enhancing and customizing their prayer experience with a supplication following the formal prayer activity. As P1 noted, “When there is a religious event, I wonder if there is any additional supplication I should do.” P6 keeps a printed Islamic calendar for observing religious events and related prayers. However, the Islamic calendar does not map easily to the Gregorian calendar since it follows lunar movements. P5 kept small printed paper notes containing supplications which he placed beside the prayer rug and read immediately after finishing the prayer.

There are different kinds of supplications; health-related, feeling lonely, sad, and so forth. P2 mentioned that she follows a TV program of a scholar who always ends her show with a supplication and she repeats after her “Amen”, but she complained that “The program is broadcasted only once a day and do not coincide with the start of any prayer time.” P2 also mentioned that sometimes she intentionally performs the prayer just before the program starts and keeps sitting on the prayer rug until the program ends for the supplication part (she engages herself in a form of one-way online prayer).

Challenge 6: Finding the Direction of Mecca

Each of the six participants owns a mechanical compass that enables them to find the direction of Mecca. However, P2 and P4 reported that they often forget to take it when travelling. P4 elaborated, “I was in transit in a foreign airport and there were no Muslims

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⁵ The desire to read more Quran verses during Salah is associated with the Muslim belief that increasing the length of Salah will yield more reward from God – if performed with concentration and attenuation.
around me and didn’t know where the direction of Mecca and wanted to pray – I didn’t know what to do.”

2.3 Interview with Religious Scholar

In designing an interface for a religious ritual, the relevant religious rulings must be respected. If an interface is deemed inappropriate by religious scholars, it will be rejected by the laity. Hence, the religious rulings pertaining the ritual impose constraints on the interface design. The best route to avoid poor design choices is to consult a religious scholar who is considered an expert in the ritual.

A semi-structured interview was conducted with Professor Iqbal Nadvi (2009), a religious scholar and university professor who obtained a PhD in Islamic law from Ummal Qura University, a respected religious institution in Muslim countries. The interview focused on the problems faced by Muslims during Salah and on the development of a digital user interface for assisting users.

The findings from interviewing participants were presented to the scholar for commentary. The scholar noted that challenges 3 (performing prayers correctly) and 4 (remembering verses from scripture) are often raised by members of his congregation. The most repeated inquiries the scholar receives are around the validity of Salah after committing an error. Nadvi differentiated between healthy adults versus those with depleting cognitive conditions, sick or elderly. Nadvi clarified Islam’s position; “while it is good to have a tool that helps such category of challenged users, their performance is still accepted by God regardless because of their condition. God does not hold the in the individual accountable for things the individual cannot control”. For healthy adults, the
scholar stressed that the key to performing the Salah correctly is concentration and asking assistance from God. Regarding challenge 5 (customizing prayer), Nadvi noted that he sometimes receives requests for clarifications about which supplication is best for a certain concern. “With so many unreliable websites putting information about the use of specific supplications after Salah – people get confused and come asking about the validity of such supplications and which one to use”, he added. Regarding challenge 2 (logging prayer performance), if an individual mistakenly thinks that he performed a prayer while he did not, the religion’s position is that he will not be held accountable because the individual did not mean to ignore the prayer duty. However, Nadvi added “if there is a tool that helps confirm to the individual whether he prayed or not, the person would be rewarded – by God – for his usage of the tool because he is sincere in trying to fulfill God’s order of perfecting the prayer”.

Regarding the use of technology during a ritual, the scholar clarified that the use of technology for religious purposes was not prohibited and that “tools were developed in the past to help in the performance of rituals, for example, the Saphaea Astrolabe.” The scholar added, “In Islam, everything is permissible unless it is stated otherwise in the Quran, tradition of the prophet, or agreed upon by the majority of the Muslim Scholars.” Hence, the introduction of a new tool to assist in performing prayer does not by itself violate any religious rule. However, three constraints were specified by Nadvi:

Constraint 1: Ritual Composition

Nadvi stressed that the ritual compositions, constituent steps and related rules are all “ordained by God” and hence they should not be changed in any way. This is a serious constraint since adding any explicit interaction technique, such as using a wrist-mounted
device, vision based interaction using eye movement and dwelling, or input via audio commands, will be viewed as modifying a sacred ritual, and thus religiously inappropriate.

**Constraint 2: Ritual Quality**

The scholar mentioned that “God looks at the quality of the prayer performed and not just the mechanical movement.” Hence, any form of interruption (e.g., error dialogs and audio alerts) leading to the loss of concentration would be deemed unacceptable.

**Constraint 3: Role of the Believer in the Prayer**

The scholar mentioned that the “believer must lead the prayer not the device – the device must never be in control, telling the believer do this or that. It is the responsibility of the believer to conduct the ritual correctly.” For example, if a tool capable of displaying scripture pages during the qayam step\(^6\) it should not force the user to read any Quran pages before proceeding to the next step. The user should have the freedom to make the prayer shorter by moving to the next step and thus interrupting the display of scripture.

### 2.4 Discussion

Based on the identified challenges from the six practicing Muslims, there seemed to be a need for a new device, with an interface designed specifically to fit Muslim prayer, or Salah. This device, however, must also respect the constraints as outlined by the scholar. The following requirements\(^7\) were derived from the interview results to guide the design:

**Requirement 1: Notify the User of Prayer Time and Religious Events**

The most requested feature by the participants was a tool to notify them of the onset of

\(^6\) Illustrated in Figure 2.1b.

\(^7\) Challenge(s) and/or constraint(s) that motivate a requirement are listed between brackets.
prayer time as well important religious dates (meeting challenges 1 and 5). Participants were already using a variety of tools, but none seemed to work in all situations. The author decided that the new design should include an overt notification of prayer times through the playback of audio recording of the call to prayer. The device will also display reminder messages of important religious events.

Requirement 2: Track Performance of Prayer

The device should maintain a record of performed prayer and enable the user to query the prayer log (meeting challenge 2). Because each of the five daily prayers has a fixed number of steps and must be performed within a specified time range, it is possible for the system to detect whether a prayer has been performed or not.

Requirement 3: Enable Access to Religious Scripture during Prayer

The device should provide means for displaying the Quran pages during prayer. Since users will neither be able to hold the device during prayer nor interact with it using traditional techniques (i.e. via keyboard, mouse, hand gesture or audio input), the device should provide alternative interaction techniques that work for users without disabilities, seniors and deaf/hard of hearing users. At this time, blind users are not being considered for this first iteration of the system (meeting challenge 4).

Requirement 4: Use Interaction Techniques That Will Not Add to the Ritual

Designing a new interface often involves inventing a vocabulary of interaction techniques: hand and body gestures, audio commands, key or pen strokes, new widgets, and so forth. However, in the case of religious rituals this is not possible as it will be perceived as a violation of the relevant religious rulings (constraint 1). Instead, the author decided to limit the interface vocabulary to the constituent steps of the ritual. Hence, the
interface must detect which step in the ritual the user is performing and act accordingly without requiring any actions/interaction with the interface on the part of the user.

Requirement 5: Assist in Correcting Errors

If a Muslim unintentionally misses or changes some of the body gestures or steps, an apologetic gesture is performed at the end of prayer. The system should detect and track the errors related to the physical actions that occur during prayer and then notify the user, in an appropriate way respecting the constraints outlined, to perform the apologetic step if the user misses performing it (meeting challenge 3).

Requirement 6: Provide Full Control to the User

The main concern of the religious scholar is to ensure that the device does not control the prayer but remains the responsibility of the individual (constraint 3). Hence, the interface should not recommend any next steps to perform, nor should it force the user to perform a step before moving to the next one. For example, in the case of correcting errors (challenge 3), the interface can detect instantaneously that the user has committed an error, but should not notify the user until she has finished the current step and enters the next.

Requirement 7: Provide Customization to the Prayer Experience

The system should support prayer customization to enhance the user experience (meeting challenge 5). Two types of customization will be supported: customization based on context in which certain verses from the scriptures can be automatically selected for display during prayer, and user-based customization in which the user is given the freedom to select parts of scripture to read during prayer. A menu/button based setup will enable the user to choose from either type for each of the daily five prayers.
Requirement 8: Support Pre-Prayer and Post-Prayer Supplication

The system should display Quran and prophetic supplication before and after the prayer (challenge 5) for the user to read. The interface should also enable users to input their own supplication.

Requirement 9: Support Direction Finding

The system should enable the user to find the direction of Mecca (challenge 6).

Requirement 10: Avoid Degrading the Quality of Prayer

In order for the system to be religiously acceptable, evidence is needed to demonstrate that using it will not negatively affect the quality of prayer.

A system satisfying requirements 1 to 9 may help users overcome the identified challenges as well as respect constraints 1 and 3. Requirement 10 involves understanding and evaluating the impact on concentration, attention and attenuation of the user during the ritual (constraint 2). Chapter 5 is dedicated to determining that constraint 2 is respected by the new system.

2.5 Conclusion

Prior to the launch of the design activity, two independent interviews were conducted; a narrative interview with six practicing Muslims about their prayer experience and a semi structured interview with a religious scholar pertaining religious rulings that might alter the design course. Results of the two interviews were presented and discussed. Nine requirements were identified based on the two interviews; notify the user of prayer time and religious events, track performance of prayer enable access to religious scripture
during prayer, use interaction techniques that will not add to the ritual, assist in correcting errors, provide full control to the user provide customization to the prayer experience, support pre-prayer and post-prayer supplication, and support direction finding.
Chapter 3

Survey of Religious Rituals and Tools

The area of tools and interfaces for religious rituals is a new area in HCI. This chapter presents two comprehensive surveys of the different types of prayer rituals and the tools that were invented to aid in ritual performance. Although this dissertation focuses on Islamic prayer, other religions’ rituals and tools were also reviewed to provide a complete overview of this new area. The goal is to enable HCI researchers to understand the design constraints as well as possible enhancement opportunities. In secular tasks, task analysis and usability evaluation are performed to obtain a reliable measure of the difference between the prescribed task and how the activity is actually performed, which typically lead to task model and design modifications. In religious tasks, many task rules must be followed in a strict manner and there is no chance for redesign. Instead, the designer is required to invent a tool or an interface that will neither change nor interfere with the prescribed task. Hence, a successful tool is one that not only provides useful functionality but also respects the religious rulings pertaining the ritual it is designed to support – while also taking maximum advantage of any flexibility in those rules. An ideal tool would be one that is weaved into the environment and does not require the user to learn any new skills. Although some content extends beyond the usual scope of HCI, it provides the reader with essential context, thus uncovering the complexities involved in designing for religious tasks.
3.1 Tools Supporting Religious Rituals

3.1.1 Taxonomy of Tools

In this section, a review of the space of religious tools is presented, with an emphasis on interaction techniques and tool design. Tools for supporting religious tasks can be classified according to their origin and according to their function (Figure 3.1). Each subdivision in the taxonomy has implication on the tool design, enhancement opportunities and restrictions. Following is a description of the various categories in the taxonomy;

*Categorization by Origin*

The origin of a tool fall into one of two categories, *prescribed* or *non-prescribed*. Prescribed tools are those that have religious significance – either because they were mentioned in the scriptures, or because the founders of the religion recommended their use. Non-Prescribed tools are those that are used for their utility and which do not have particular religious significance. It is important to identify which category a tool falls under early on in the design process. If a religious tool falls into the *prescribed* category, then design modifications to create a new digital user interface or interaction technique,

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8 Categories are italicized.
may be subject to major constraints. Understanding what is exactly sacred about a tool is vital to the design activity. In the case of non-prescribed tools, there is likely to be more flexibility in the redesign. The Hanukkah Menorah, shown in Figure 3.2a, is an example of a prescribed tool. A nine branched candelabrum which has been a symbol of Judaism for thousands of years. When utilizing a menorah as an interface, the designer must therefore respect the original design. It is significant that there are nine candles, aligned in a straight line with one visibly differentiated from the remaining eight, and also that light comes out from all of them. For example, making one of the candles emit more light than the others, to communicate information in an ambient way, should only be done after consulting with the appropriate religious scholars. The Buddhist prayer wheel (Figure 3.2b) is another example of a prescribed tool on which prayers or mantras are written. According to the Tibetan Buddhist belief system, spinning such a wheel will have much the same effect as orally reciting the prayers. The concept of the prayer wheel is a physical manifestation of the phrase "turning the wheel of Dharma" which describes the way in which the Buddha taught. The sacred concept in this design is the cylindrical shape which enables rotary movement and it is not the physical object itself.

![Figure 3.2: Prescribed versus non-prescribed tools. (a) Hanukkah Menorah – from (Menorah, 2011). (b,c) Mechanical and electrical Buddhist wheels – from (Prayer Wheel, 2011).](image-url)
Consequently, an electric wheel – such as that in Figure 3.2c – is religiously equivalent to the traditional mechanical version.

**Categorization by Function**

Using a tool in a religious ritual is motivated by one or more of the following five goals: supporting *prayer*, handling *scripture*, invoking a *blessing*, determining *geo-temporal* information or *compliance* with a religious ruling.

The rosary (Figure 3.3a) is an example of a tool used in prayer. The design could be considered one of the oldest tools exhibiting Norman’s affordance (Norman, 1988), whereby the shape of the object facilitates smooth interaction. The beads are divided into sections by a flat separator, with the number of beads in each section indicating the number of times that the believer should repeat a religious phrase. The user slides a bead over the index finger using the thumb finger. The flat separator is a signal to the user to stop repeating one phrase and move to the next. The spherical shape of the beads makes it easy to slide across fingers, and their circular arrangement signifies the religious concept that the act of worshiping "God" is endless since once one circuit is finished, another one can be started. An example of the tool for handling scripture is the Torah pointer (Figure 3.3b) which is used to point to the scripture during the reading from the parchment Torah scrolls. This tool is intended to prevent the user from touching the parchment, which is considered sacred according to Jewish tradition. The reader is therefore required to use a pointer to follow his or her place in the scroll. Buddhist sticks (Figure 3.3c) are an example of a blessing tool – used when a user wants to know if the Buddha blessed a certain decision. The sticks have numbers written on each of them. The believer takes the cup, asks a question in the heart and shakes the sticks. After several shakes, one of the
sticks falls from the cup and the next procedure will be asking for confirmation. The Astrolabe (Figure 3.3d) is an example of a geo-temporal tool used by Muslims. The tool consists of a set of sphere with multiple concentric pointers mounted on. The user rotates the sphere until the pointers align which will reveal the correct geo-temporal information. The Astrolabe was used to find the interval for the five daily prayers for each day in the year, the direction of Mecca, and other religious geo-temporal information useful for Muslims. The Kosher Lamp is an example of a compliance tool. An electric lamp which complies with the Jewish ruling that one should not turn a switch on or off on Saturday (Kosher Innovations, 2007). Shown in Figure 3.3e, the user rotates the top of the lamp and the cover obstructs the light. The cover material allows heat to escape safely from the lamp while blocking virtually all the light, without any need to turn off a switch.

![Figure 3.3: Examples of non-prescribed tools. (a) Rosary – from (Rosary, 2009). (b) Torah pointer – from (Yad, 2009). (c) Blessing sticks – from (Buddhist Practices, 2008). (d) Astrolabe – from (Astrolabe, 2009). (e) Kosher lamp – from (Kosher Innovations, 2007).](image)

### 3.1.2 Digital Tools in Light of the Tools Taxonomy

Digital technologies, such as embedded systems, the web and wireless technologies, have paved the way for new tools supporting religious tasks. This section includes a survey of these tools – classified according to the Tools taxonomy presented in section 3.1.1 – accompanied by a design critique from an HCI perspective.
Prayer Tools

Since prayer is a fundamental component of any religion, several designers have tried to produce electronic versions of prayer tools. However, most of these tools did not undergo a formal study to evaluate their usability. Popularity did not spread beyond the research labs they were developed in.

Two designs have already been proposed to integrate the rosary functionality in everyday tools; the iRosary and the iSubah. The iRosary (2007) combines a rosary and an iPod (Figures 3.4a & 3.4b). The most distinguishing feature of the iPod, the white earphones cable, becomes a rosary string with just one bead. This one bead can be shifted, and its position measured and heard as "audio beads" along a sensitive range of the cable, replicating the pattern of the rosary beads. The technical possibilities of the iPod can also be used to help a practitioner to learn the prayers; the right mysteries are inserted automatically based on the iPod’s integrated calendar and there are various modes for choosing the degree of difficulty. Despite of the apparent innovation, the iRosay lacks the advantages associated with the traditional design of prayer beads. The traditional prayer beads were designed to be operated by a single hand in rest position while the iRosary requires the user to extend the arm towards the upper chest to move the bead, the latter being an awkward movement. Furthermore, the iRosary lack physical markers to indicate the current position along the cable while the circular arrangement and the presence of many beads, in the traditional version, provides the user with immediate haptic feedback regarding the progress of prayer. On a more philosophical level, the beads have been placed in a circular arrangement, to signify that once one circuit is done, the user can immediately begin another one since worship is endless. Sliding a single bead in a linear
fashion does not provide an equivalent metaphor. An even more radical departure from the traditional rosary is the iSubha (2009), which is an iPhone application using a touch-based interface (Figure 3.4c). The user touches one of the virtual beads every 11 counts. The application stores the counts and times and enables the user to continue from the last location saved. The design provides more functionality than traditional rosary but the form does not feel like a rosary and is harder to use since the user needs to look carefully where to touch to update the counter. Traditional rosaries are operated without even looking at the beads.

![Figure 3.4: Digital rosary. (a,b) iRosary – from (iRosary, 2007). (c) iSubha – from (iSubha, 2009).](image)

In another type of interface, Hlubinka et al. (Hlubinka, Beaudin, & Tapia, 2002) developed a web-connected version of the traditional Christian altar. AltarNation (Figure 3.5) is a digital system that allows remote individuals to form communities of meditation and to tailor their own meditative practices. The work borrows from existing Christian prayer practices. By lighting candles, users enter a shared virtual community of users represented by a field of stars, each associated with a sound sample of a prayer, song, joy, or a concern of another user. Although an iconic representation communicates the virtual
presence of a user, earlier works in HCI and computer supported cooperative work suggest that a better design alternative is to show the participants’ images and display the performed actions directly. Face-to-face dialogue can be more engaging than symbolic representation because of the added elements of gesture and body language. Interestingly, using online presence can facilitate healing as demonstrated by a study of patients coping with breast cancer (Shaw et al., 2006). Thus, this type of interface could find applications in medical care centers – in addition to remote locations.

![Diagram of the AltarNation system](image)

**Figure 3.5: The AltarNation system – from (Hlubinka et al., 2002).**

Modern prayer tools are not limited to physical form, but extend to the web, which is becoming a strategic location for religion (Wyche, Hayes, Harvel, & Grinter, 2006). There are hundreds of websites supporting online group prayer. As an example, the Virtual Jerusalem (2007) project uses the web to deliver prayer to the Wailing wall in Jerusalem. A Jew who desires to put a prayer in the Whaling Wall can do that by sending an email to the website. The email is automatically printed and placed in an envelope – to protect confidentiality – for the website staff to pick and deposit in the wall.
The popularity of religious websites shows that believers are; willing to participate in remote religious activities, willing to share their personal religious beliefs with strangers who share these beliefs, and looking for non-traditional ways to enhance their spiritual life. These observations are supported by many surveys and social studies. For example, the Pew Internet and American Life Project revealed that 64% of Americans who go online have used the internet for religious or spiritual purposes (Hoover, Clark, & Rainie, 2004). From an HCI perspective, designing an online group prayer service where users are remotely present is challenging because there is a need to convey all of the following; the spiritual atmosphere that is often present in a physical space, the face to face interactions that happen between practitioners during prayer, and the group feeling which unite the practitioners while praying.

Scripture Tools

The Living Torah project is an example of an augmented interface that attempts to use modern technology to add context to scripture. In this project, Lindenberg (2007) attempted to enhance the Jewish holy book reading experience. Because the actual scroll must not be touched by hand, the Rabbi uses the Torah pointer, or Yad, as a reading aid. Lindenberg intervened in this process by making the Yad tractable via computer vision. The current position is analyzed and a translation from ancient Hebrew into modern-day English is projected onto the physical scroll on the table (Figures 3.6a & 3.6b). Lindenberg’s preservation of the form and functionality of the Yad while providing the user with an experience that cannot be achieved without digital technologies is an example of a successful augmentation of a religious tool. A major drawback though is the complex system required to enable the interaction: a ceiling-mounted projector, a camera
and computer system capable for processing the vision input in real time.

E-Qalam (2010) is a new educational technology for Muslims to help the user recite the Quran correctly (Figure 3.6c). The Quran, a book of 624 pages, has phonetic recitation rules that many Muslims are keen to learn. The system consists of an embedded controller in a pen form and a specially coded Arabic Quran pages. The user points at a specific verse with the pen and click one of the pen buttons with the thumb to listen to the correct recitation of the verse being pointed to. The pen has a sensor at the tip that reads a unique code for each verse. The codes are printed on a separate layer which is invisible to the user. Embedding magnetic codes in Quran pages enabled the designer to present the user with the scripture pages unmodified which is important to respect the religious rulings. The user can select between fast and slow recitation, as well as four translations of the verse. The form of the device, with the buttons close to the thumb finger, makes it usable with one hand – an important factor since users typically hold the Quran in the other hand. Although no formal evaluation has been done of the E-Qalam, yet one can draw analogies with earlier HCI works. Paper-based audio notebook (Stifelman, 1996), listen reader (Back et al., 2001), and books with voices (Klemmer, Graham, Wolff, & Landay, 2003), all embedded electronics in traditional books and their

![Figure 3.6: Scripture tools. (a,b) Living Torah – from (Lindenberg, 2007). (c) E-Qalam – from (E-Qalam, 2010).](image)
evaluation revealed the usefulness and effectiveness for users

Another type of scripture tools are digital scripture readers, typically a handheld device which displays the scriptures and provide search and indexing functionalities. Manufacturers intentionally prevent users from the ability to modify the stored information or store/access additional information – in an attempt to present these as equivalent to printed scripture. Although religious scriptures can be viewed on other handheld devices, dedicated scripture devices are gaining more popularity (Pathoni, 2007). Users tend to think of these scripture devices as a more representative form of the printed scriptures – unlike an iPod, for example, which can be used at one time to display the scriptures and at another time to display other types of documents.

Blessing Tools

Buddhist tradition teaches that a believer can ask if Buddha will bless an action by throwing two small wooden pieces called Bue (Figure 3.7a). Depending on the way the Bue land, the answer to the question is "yes", "no" or "smile". A smile indicates that the believer should throw the Bue again. Wu (2006) recreated the practice, using embedded technology. In Wu’s adaptation, the pieces are made of acrylic and equipped with either red or blue LED (Figure 3.7b). The user throws them into a box (Figure 3.7c) that also contains a two-colored Image of Buddha (Figure 3.7d). Depending on the way the Bue land, Buddha's facial expression looks different, thus simplifying the interpretation. In this work, the designer has preserved the interaction techniques associated with the traditional tool. However, the added advantage of using such a re-implementation is unclear. A traditional Bue will provide exactly the same functionality and is cheaper.
Another example of a blessing tool is the Crucifix NG (Malkin, 2006) – which is a printed circuit board (PCB) in the shape of a crucifix. Observant Christians often affix Crucifixes to the wall of their homes for metaphysical security. Malkin embedded a battery-operated transmitter in the crucifix PCB to broadcast an ASCII Christian prayer at a free bandwidth. The signal is strong enough to cover an average size room and can be received by any object that acts as an effective antenna including the human body. This type of device raises questions pertaining religious freedom since it is beyond anyone’s ability to accept or reject the transmission. It also highlights a design challenge; how to not invade the privacy of believers of other religions – while designing for a particular group of users.

*Geo-temporal Tools*

One of the earliest digital geo-temporal tools is IslamicFinder’s Azan (Wasat, 1998), a MS Windows application, that runs as a background service, and notifies the user with the onset of prayer intervals during the 24 hours. Muslims are required to pray five times a day – once during each of five designated intervals: between dawn and sunrise, between midday and afternoon, between afternoon and sunset, between sunset and dusk, and between night and sunrise. The exact time of prayer intervals changes every few days due to the movement of the earth in relation to the sun. The software simplifies the task of working out prayer times by calculating them based on the date and the geographical
location of the user. At the appropriate times, the software plays an audio notification compliant with Islamic rules.

With over 20 Mn downloads, Azan is probably the most popular digital tool for supporting a religious rituals. Although the software accomplishes the goal it is made for, there is potential for usability enhancements. The software does not warn the user that the current prayer interval is about to expire and the next prayer interval is approaching to give users enough time to perform the current prayer before it’s time expires. Users are often surprised by the sudden audio playback. Furthermore, since the call to prayer audio is the same for four out of five prayers⁹, users sometimes still need to query the program for the current prayer interval. DenHengst et al. (DenHengst, McQuaid, & Zhu, 2004) has shown that using time based visualization does indeed aid comprehension and projection of time and increase situation awareness, which will enhance the believer’s ability to perform rituals on time.

Works in HCI related to focused and divided attention, for example; Scope Tool (Van-Dantzich, Robbins, Horvitz, & Czerwinski, 2002) and Side Show (Cadiz, Gupta, Jancke, & Venolia, 2001), as well as works related to visualization of time based events, such as those surveyed in Silva and Catarci (2000), could be used to inspire better notification interfaces. Geo-temporal functionality is also being integrated into common devices such as phones and alarms. Wyche et al. (2006) developed the Sun Dial (Figure 3.8a), an application that displays an image of the sun movement, during the day on a semi-circular track with specific markers for the Muslim prayer intervals. The image is displayed as a cell phone background, making it easily accessible – as users only need to glance at their cell phone to identify the current prayer interval and how much time is left

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⁹ Call to prayer phrases are religiously prescribed.
before it expires. The use of such religiously-relevant imagery enhances the user experience. QiblaCompass (Figure 3.8b) is an iPhone application that uses the embedded GPS to identify the direction facing Mecca – a requirement for Muslim prayer. The user rotates the iPhone, causing the virtual pointer to rotate. The pointer freezes when it points in the direction towards Mecca informing the user of the correct orientation. The interaction technique is intuitive and mimics using a physical compass – hence, there is no learning required.

![Figure 3.8: Geo-temporal tools. (a) SunDial – from (Wyche et al., 2006). (b) QiblaCompass – from (GuidedWays, 2011).](image)

**Compliance Tools**

For a compliance tool, the major design criterion is to support the user in implementing a religious rule. This type of interfaces often violates commonly used usability criteria such as ease of use, speed, accuracy, and satisfaction. Observing a religious rule or custom has higher priority than the interface aesthetics or even usability. Rabbi Yakobovitch (Nahshoni, 2007) developed the earliest set of digital compliance tools for conservative Jews: Jewish-friendly pens, telephones, mice (Figure 3.9), keyboards, electronic doors and gates, sensor-activated faucets and urinals. The Jewish law prohibits doing any form of work on Saturday, or Shabbat. Observant Orthodox and Conservative Jews do not perform 39 categories of activity prohibited by Jewish scriptures (Talmud Mishnah
These devices were developed on the basis of the Jewish Halachic concept of Grama, which means indirect action. Flipping the activation switch does not directly cause an electric circuit. Instead, internal electric scanners check the status of the switch every few seconds, and when a change is identified the operation is executed. According to Yakobovitch, there is a risk that routine operational use of this new technology will blur the religious boundaries and lead user to believe that it could be used frequently and excessively on Shabbat. For this reason, the rabbi notes “we made sure that their use would be uncomfortable, so that the user will always remember that it’s Shabbat,” (Nahshoni, 2007:1), and will know that "with a Shabbat pen you cannot write a prose or a letter to your grandmother" (Nahshoni, 2007:1). The interface forces the user to use the device only when faced with an urgent need, which in itself acts as a reminder of the Shabbat rule, to rest and not be attracted by worldly temptations.

This technology represents a new type of user interface that is deliberately made to be difficult to use – in order to respect the religious commandments. In designing secular interfaces, efficiency and effectiveness are two desirable and complementing objectives. In compliance tools, effectiveness has higher priority than efficiency. The Shabbat Mouse demonstrates a distinguishing feature of such tools; it will be perceived sometimes as
illogical from a secular perspective. To evaluate the usability, the designer must comprehend and realize the importance of relevant religious instruction to the believers. Orthodox interpretation of Jewish law treats one who does not keep the Sabbath as one who abandons Judaism for another religion (Talmud Mishnah Sanhedrin 7:4-55a).

Another example of a compliance tool is the Digital Mezuzah by Eibach (2006). The Mezuzah is a piece of parchment usually contained in a decorative case, inscribed with specified Hebrew verses from the Torah. In Jewish homes, the mezuzah is usually hung on the upper third of the doorpost, to the right side of doors going into rooms (Figure 3.10a), to imply that God and the Torah, which the mezuzah symbolizes, are blessing the room. Eibach developed the digital Mezuzah (Figure 3.10b) that can be mounted to the right of the user’s computer screen, and which warn the user if a website is not Jewish permissible, or Kosher. In this way, the digital device is believed to protect the computer just as the physical version protects a room. It is possible that Jews will find in the digital Mezuzah a stronger incentive to comply with the religious instructions, compared to a firewall software application with support for religious rules. However, no formal evaluation was made to determine if such a tool is indeed more effective.

![Figure 3.10: Mezuzah. (a) Traditional Mezuzah – from (Mezuzah, 2009). (b) Digital Mezuzah – from (Eibach, 2006).](image-url)
3.1.3 Islamic Prayer Rug in Light of the Tools Taxonomy

The Islamic prayer rug (Figure 3.11a), a piece of fabric used by Muslims is an example of a non-prescribed tool created to support prayer. Made of thin layer of fabric to be easily folded, carried around, washed, and positioned towards Mecca, the prayer rug helps to keep the worshipper clean and comfortable during the prostrations of prayer. The prayer rug typically has a line drawing or a symbol that indicates the feet side – since users do not like to have their foreheads touching where their feet did in previous prayers. According to tradition, the prayer rug should have few graphic symbols to avoid distracting the user while praying. Minimal design alternations have been made throughout history on the rug. Only recently, a mechanical compass (Figure 3.11b), to guide the user to the direction of Mecca, was added to some models. The compass is used in association with a booklet that identifies cities of the world by an index. The compass needle is set to point in the correct direction if one side is pointing to the city index while the other direction would be pointing towards Mecca. Sajjadah1426 (Özenç, 2008) is the first attempt to introduce digital technologies in the prayer rug. The device is made using

Figure 3.11: Muslim prayer rug. (a) Traditional. (b) Traditional with compass.
electro luminescent phosphor printing technology (Figure 3.12), which allows it to display various graphics on the surface. An embedded compass instructs the rug to glow more brightly as it is turned towards Mecca, allowing users to easily determine when they are oriented in the right direction. The tool presents an intuitive interaction technique and preserves the typical interaction involved in trying to find the direction of Mecca using a physical compass. However, turning the whole prayer rug into a display could affect the concentration of the practitioner. It is not clear how believers would perform on the Sajjadha compared to a regular prayer rug as no formal evaluation was done. The heat generated by the luminescent components could render the prayer rug unusable until it is cooled down. Another problem with the design is that the adopted fading visualization does not map well to a direction finding task – since fading is associated with availability or absence of light and not looking towards or away from an object.

In the next section, taxonomy of the different types of prayer from various religions is presented. Although, the prayer taxonomy was initially developed while trying to identify issues that impact the design of a tool supporting Islamic prayer, yet it is not specific to Islam.

Figure 3.12: Sajjadah – from (Özenç, 2008).
3.2 Prayer Rituals

3.2.1 Taxonomy

Prayer ritual is a complex, multidimensional construct with many existing variations. Poloma and Gallup (1991) studied different types of prayer and documented four varieties: ritualistic, petitionary, meditative, and conversational. However, this classification is incomplete for HCI research since it overlooks details that are vital for usability analysis and design activities. Instead, the task-centered taxonomy (Figure 3.13) is proposed as it covers the various issues that need to be taken into consideration. This taxonomy was built after reviewing prayer from many religions and is not specific to anyone. In the taxonomy, eight domains are identified, named and defined. A hierarchy

Figure 3.13: Taxonomy of prayer rituals.
of categories within each domain, related by strict inclusion (x is a kind of y), is also identified and defined along with the semantic relationships among the components. Following is a description of each dimension\textsuperscript{10} with examples from different religions.

\textit{Setting}

Prayer can be carried out individually - \textit{solo}, or it may be carried out corporately in the presence of fellow believers as a \textit{group}. Figure 3.14 shows the adherents of three different religions in a group setting. \textit{Group} prayer can be conducted \textit{without a leader} as in the case of the Mormons (Figure 3.14a) and Protestants (Figure 3.14b) or \textit{with a leader} as in the case of Muslims (Figure 3.14c). Religious teachings usually provide guidance or instructions on how a group prayer should be conducted. What will work for one type of group prayer might not work for another. For example, a Muslim might start performing a \textit{solo} prayer and others join the prayer after the \textit{solo} prayer has begun – converting the prayer to a \textit{group} prayer where the first person will automatically lead. The setting must therefore be considered as a possible constraint in the development of a tool. A table-top interface could be used to support a Christian prayer since adherents often sit or kneel in

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Prayer.png}
\caption{Group prayer (a) Without leader – from (Mormon Prayer, 2010) (b) Without leader holding hands – from (Christian Prayer, 2010) (c) With leader – from (Prayer, 2010).}
\end{figure}

\textsuperscript{10} Domains and categories are italicized.
a circular arrangement, but the designer should not require the users to interact using their hands – since holding hands is part of the setting.

**Ruling**

Prayer can be a required task which every adherent must perform – mandatory – or it can be an optional task that adherents chose to do when they feel a need. A single religion, as in the case of Islam and Judaism, may include mandatory as well as optional prayers. In developing a tool, it is necessary to take into account the different prayer ruling. Mandatory prayer requires a notification mechanism to ensure that the user performs it at the right time, date, or place.

**Text**

During a prayer, the believer might communicate with the worshipped deity using his or her own words – *freeform*, by quoting specific religious verses – *recite*, or by *singing* religious phrases. Singing could be done in chorum where every member, or group of members, of a large congregation, has a different role in the prayer. The verses or phrases used will either have been memorized by the user or will be read from a book or some other document. Some religions, such as Christianity, allow the user to hold a book or prayer notes (Figure 3.15), while others, such as Islam, do not recommend this practice in mandatory prayer. In addition, a prayer could be using loud voice – *vocal* – or in *silent*. The handling of text could be a design constraint since not all religions will allow the believer to hold a physical device to read the prayer’s text. Similarly, if the prayer is *silent*, the user’s voice cannot be used to trigger events and the interface has to resort to alternative input techniques, such as eye tracking, head movement, or body gesture detection.
Participants

In religions with theological administrative body – for example Catholic Christians – believers are generally classified into laity or priest. The word priest is used in a general sense here to refer to women/men of religions. Priests would have different rulings compared to the laity. For example, in the Druze faith, the laity is not required to pray at all (optional), while the priests are required to pray (mandatory). In such cases, a tool will need to support these different categories of participants. In a group prayer with a leader, a tool supporting the leader character – priest, will suffice since he/she controls the activity.
**Duration**

The amount of time a prayer takes is an important factor to consider in design. Some types of prayer can be carried out in a very short duration of time – *arrow*. Those are typically situational and use prescribed set of verses. An interface needs to be aware of the user context and needs to remind the user of the appropriate arrow prayer. No opportunity is often permitted for soliciting user input. Arrow prayers are often invoked when the user feels stress, fear, anxiety or surprise. Physiological measures could be used to illicit user mode but the detection of the context could be harder. If the user utilizes an electronic calendar, to-do list or task planner, then those could be used to determine the context. Electronic devices with location detection means could be also utilized to provide context. For example, if the user is in a hospital, appropriate verses related to health could be displayed to the user to read – which might help in alleviating and controlling stress. Most prayers fall in the *short* category which could last from few minutes to 30 minutes. The times, context and exact duration of those prayers could be known from the religion’s tradition. Some religions have *long* prayers that last for hours. In this case, the challenge in the interface design is to not exert any further physical demands from the user since the task at hand is already physically and emotionally consuming.

**Activity**

Prayer rituals might consist of a simple body gesture – *simple*, as in the case of the Christian kneeling gesture shown in Figure 3.16a, and the Hindu floating body gesture shown in Figure 3.16b. In other religions, the involved rituals are more complex and may require several different body postures. In Buddhism (Figure 3.16c) and Sikhism (Figure
3.16d), the body posture is defined by the religion but the sequence of movements is not defined – *improvised*. In Islam, the type and order are specified by the religion – *prescribed*. A Muslim prayer is invalidated if the believer changes the order intentionally (Zulfiqar, 2006). If a Muslim unintentionally misses or changes some of the body gestures, then an additional apologetic gesture is performed at the end of the prayer. The ritual type is another design constraint on a tool since having user interface controls, such as buttons – physical or virtual, is not suitable if the religion does not permit the believer to do any additional gestures except the prescribed ones. A successful tool must also recognize all the performed postures.

![Figure 3.16: Prayer postures](image)

**Figure 3.16: Prayer postures (a) Christian – from (Bible Prayer, 2010). (b) Hindu – from (Hindu Awakening, 2010). (c) Buddhist – from (Picture China, 2010). (d) Sikh – from (Sikh Prayer, 2012).**

**Goal**

A prayer can have one or more goals. The ACTS (*adoration, confession, thanksgiving, supplication*) a Christian prayer model, have been used to illustrate and categorize motives behind prayer. In addition to the four identified types, *contemplative* and *surrender* have been added since they are practiced by East Asian religions. If the focus is on the worship and praise of a "God", without reference to specific circumstances or needs; then it is referred to as an *adoration* prayer. If the prayer involves acknowledging faults, misdeeds, or shortcomings, it is known as a *confession* prayer, while if the prayer
requests “God's” intervention in specific life events for oneself or others, it is called *supplication* prayer. A *contemplative* or receptive prayer is a type of prayer in which one more passively awaits divine wisdom, understanding or guidance. It is important to note that one prayer might combine several goals and in some religions, such as Islam, a specific step in the ritual is considered the best to achieve one of those identified goals. A successful interface must be able to accommodate the different types of prayer in the religion by displaying the appropriate phrases and providing correct contextual information related to the ritual.

*Time/Date*

Time and date plays an important role in a prayer. Some religions require their believers to perform prayer on certain dates and at specific times – *fixed*. For example, in Hinduism, which regards taking a "bath" in a fresh water river or lake as the most important daily ritual, 4:00AM is considered to be the most auspicious time to do so. Each of the five daily prayers in Islam (morning, noon, mid-afternoon, sunset and evening) must be performed within specific time limits – *interval*, but there is no specific fixed time assigned to each. A successful tool must notify the believer that prayer time is approaching or has arrived. In some religions, the believer is required or recommended to perform a body cleansing ritual before the prayer, for example, Islamic wudu (ablution) and Jewish tahara (purity). Consequently, a notification should leave enough time for such activity and perhaps detect if was not performed or performed incorrectly. The constraints associated with specific times and dates are extended, in some religions, to include the type of interactions the believer can perform with the surrounding
environment. For example, in Judaism, Shabbat\textsuperscript{11} is the weekly day of rest and Jews are forbidden from many interactions on this day. Therefore, a Jewish tool would need to support interaction techniques that do not violate the rules of Shabbat.

3.2.2 Salah in Light of the Rituals Taxonomy

Considering the taxonomy presented in section 3.2.1, Salah has the following attributes. The ruling is \textit{mandatory}, since an adult Muslim is required to perform it. The ritual consists of prescribed and ordered steps (Activity--order: \textit{prescribed}). The activity consists of several steps and gestures performed in place (Activity--body gesture: \textit{complex in place}). Regarding goals of Salah; \textit{surrender}, \textit{adoration} and \textit{thanksgiving} are exercised in the physical postures and used phrases. Optionally, the practitioner might perform \textit{confession}, and \textit{supplication} during Salah. Time/date is \textit{interval}-based, since each of the five daily prayers is performed within defined time intervals. Salah’s duration is \textit{short} – lasting few minutes. Regarding Salah’s setting, a Muslim can either perform the ritual \textit{solo} or in \textit{group with leader}. The used text is \textit{recited} from memory and the recitation mode is either \textit{vocal} or \textit{silent}\textsuperscript{12}. Since in Islam there is no priesthood, all participants are considered \textit{laity}. However, during group prayer, one person is designated as the group leader.

3.3 Conclusion

This chapter aimed to uncover the many peculiarities and subtleties of religious rituals

\textsuperscript{11} Shabbat is Saturday in Hebrew.
\textsuperscript{12} Sunrise, sunset and night Salahs are vocal while noon and afternoon Salahs are silent.
and the tools to support them. The biggest gap that currently exists in front of HCI researchers contemplating to work in this new area is an information gap. Two taxonomies, for religious rituals and for tools, were created to fill that gap. Related digital tools and interfaces were also surveyed in the light of the proposed tools taxonomy. The surveyed related HCI works show the need for detailed background information about religious rituals. For example, AltarNation (Hlubinka et al., 2002) though suitable for free form Christian prayer, it does not facilitate more structured ones. In Churches, believers use prayer cards (Figure 4.15) to read specific verses from the bible related to a particular context. Had AltarNation included a computer display, other forms of prayer would have been possible.

A tool can either be non-prescribed or prescribed – the later has more restrictions which could limit the design choices while the earlier is easier to change. For example, the Muslim prayer rug’s form, material and usability can be modified without raising concerns about being religiously acceptable or not. The religious rituals taxonomy demonstrates that a designer should consider eight dimensions when designing for a ritual, namely: setting, ruling, text, participants, duration, activity, goal and time/date.

The survey of modern tools show that user interface and system design targeted to support religious rituals have been going on for several years. However, most of the work has been done outside the realm of HCI research and guidelines. Consequently, the majority of new designs have not been evaluated formally and their utility and effectiveness is not known.
Chapter 4

Design Evolution of the Electronic Prayer Rug

4.1 Design Alternatives

In order to support Salah, a user interface must detect the different body postures performed\textsuperscript{13}. Most body-posture tracking work has been performed using vision systems or with special sensors (Figure 4.1). Researchers have used optical, acoustic, or magnetic techniques (Durlach & Mavor, 1995). Typically, the user must wear markers that are detected by special high resolution cameras. Three-dimensional analysis software is then used to interpret and modify an existing 3D virtual model of the user to determine the current posture. These systems have the disadvantages that the size of the captured room is limited in space, that they are often installed in a fixed place, and that the user must wear special markers. This is not a limitation when capturing one time or special events, for example, gait analysis. However, for finding inappropriate movements within daily activities, such as a prayer task, motion tracking systems would not be practical since the camera view of user’s body could be obstructed by common house objects, the user might feel uncomfortable due to the mounted markers, or might forget to wear them.

De-Rossi (De-Rossi et al., 2000) integrated sensors directly into clothing. Having the sensors in a garment has the advantage that the sensors do not disturb people during daily activities. However, these systems are still experimental and the user might feel uncomfortable because the garment is often more rigid compared to commercial cloth and he must wear the same garment for each session. Hansson et al. (Hansson, Asterland,

\textsuperscript{13} Illustrated in Figure 2.1.
Holmer, & Skerfving, 2001) developed body-mounted transducer accelerometers. However, these sensors are several centimeters in size and, therefore, not practical. As an alternative, Tollmar et al. (Tollmar, Demirdjian, & Darrell, 2003) used stereo cameras and a 3D virtual model of the user to detect a limited set of body gestures. However, such computer vision-based techniques require the user to wear cloth that is color contrasted with the background for the image segmentation to work – which makes them again impractical. Another method is an ultrasonic distance measurement directly on the skin (SonoSense, 2008). This product has been commercialized and is used to measure the posture of the back, but is only applicable for restricted movements.

![Figure 4.1: Body gesture detection techniques.](image)

(a) Computer vision with markers. (b) Body-mounted sensors – from (Hansson et al., 2001). (c) Textile augmented sensors – from (DeRossi et al., 2000). (d) Computer vision without markers – from (Tollmar et al., 2003).

After considering each of the existing methods for posture detection, augmenting the traditional prayer rug with digital sensors seemed the least intrusive and most versatile approach. Users expect the prayer rug to be light, portable, and usable everywhere
regardless of the light conditions or background colours. Requiring the users to wear special cloth or mount markers on their body is impracticable as well.

A decision was made to augment the traditional rug with a screen for displaying scriptures to the user during prayer and digital sensors for detecting body positions. A prayer rug is often used by Muslims during their prayers. Hence, no learning is required to understand how to use a prayer rug; the user will only be required to replace an existing tool with a similar but digital one. A popular physical tool often has qualities which enable the user to perform the task, for which the tool was designed, effectively (Norman, 1988). Embedding electronics into such physical objects, while preserving their original functionalities, has repeatedly been shown to be a successful interface approach - as evident by many works from ubiquitous computing. For example, the HoloWall (Matsushita & Rekimoto, 1997), Anoto digital pen (Löwgren, 2000), DimamondTouch table (Dietz & Leigh, 2001), I/O Brush (Ryokai, Marti, & Ishii, 2004) and SmartSinks (Leonardo, Arroyo, Lee, & Selker, 2005) are all digital interfaces constructed by embedding electronics in a form factor that mimics known passive physical objects such as walls, furniture and household fixtures. The form factor affords its common use so that users are able to understand how to enable or interact it with. Digital enhancements and interface techniques then enhance the functionality. Researchers not only preserved the traditional physical form but also were keen to select interaction techniques that are affordable by that form.

The initial concept of the electronic prayer rug (eRug) was envisioned to consist of proximity and touch sensors embedded in the rug to detect user postures, a screen for displaying scriptures and notifying users of errors, and two LED notification bars placed
along the sides of the rug (Figure 4.2). The notification bars would serve two functionalities; to indicate how much time is left in the current prayer interval and to alert the user if the prayer for the current interval has not been performed yet. By glancing at the progressively illuminated white and red LEDs\textsuperscript{14}, the user could obtain an estimate of the remaining time. If the user already performed the prayer, blue LEDs would be switched on serving as a memory aid.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4_2.png}
\caption{eRug design concept.}
\end{figure}

4.2 Design Iterations

An iterative design process was followed resulting in four incremental versions of the eRug. In each iteration, heuristic evaluations and pilot in-lab usability studies were conducted leading to improvement in the design. The scholar’s input was also solicited, for each iteration, to ensure that the eRug hardware and software conformed to the religious rulings. Meetings with the scholar also involved brainstorming sessions during

\textsuperscript{14} Red LEDs alert the user that the time for the current prayer is expiring soon.
which possible useful uses of the eRug were discussed from a technical and religious points of view. The following sections provide a description of each version and a summary of the preliminary evaluation\(^\text{15}\) results and the scholar’s input.

### 4.2.1 Iteration 0: eRug - Wood Prototype

**Hardware**

A low-fidelity wood prototype was constructed to illicit initial feedback from the scholar and users. The prototype was made using a wooden panel, 120cm (47") x 70cm (27"), covered by a traditional prayer rug. The wooden panel had holes cut through for the electronics which were mounted from the backside (Figure 4.3). Wood was chosen to protect the electronic circuitry inside the eRug since the user’s weight might damage the components. For detecting user posture, Sharp infrared range sensors, GP2Y0A, were used. These sensors can take a continuous distance reading, within a range of 20cm (8") to 150cm (60"), and return a corresponding analog voltage. The infrared sensors were placed in three strategic locations; where the user would stand, where the user would bow with her chest, and where the user’s head would touch the panel. Touch sensors were also used and located close to the infrared sensors in order to differentiate between the sitting\(^\text{16}\) and prostration\(^\text{17}\) postures (the infrared sensors were unable to distinguish between different postures due to their limited range). A set of colored LEDs were glued along the bottom of the side which consisted of semi-transparent plastic bars (shown in Figure 4.3). A LabJack micro-controller I/O unit (LabJack, 2007), installed underneath

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\(^{15}\) Chapter 5 is dedicated to a detailed formal evaluation to satisfy constraint 2.

\(^{16}\) Illustrated in Figure 2.1f.

\(^{17}\) Illustrated in Figure 2.1g.
the wooden panel, was used to sample the touch and infrared sensors and to switch on/off
the LEDs. To display Quran verses, a tablet PC with a rotatable touch screen LCD
(shown in Figure 4.3) was embedded in the wooden panel. The LabJack micro-controller
I/O unit was connected to the tablet via USB.

![Figure 4.3: eRug iteration 0. Wood prototype with screen and back-mounted sensors.](image)

Software

Custom software to drive the prototype was developed by the author. The software
continuously sampled the infrared and touch sensors through the LabJack microcontroller
unit. Each prayer posture was treated as a body gesture which signals input events in the
software. In the standing step\(^\text{18}\), pages of Quran were displayed for the user to read. Since
users’ reading speed would vary, the amount of time a page was displayed was
configurable through the software setup interface.

The software was capable of detecting commission and omission errors. An omission
error occurred when the user forgot a step in the prayer. A commission error occurs when
the user adds a step to the prayer while under the incorrect assumption that it was not
performed. In addition, the software implemented the prayer interval and prayer

\(^{18}\) Illustrated in Figure 2.1b.
performance notification mechanism – as described earlier – by switching on/off the LEDs through the LabJack unit.

**User Interaction**

The software provided a menu based interface which was accessible via the touch-screen LCD. Prior to the commencement of Salah, the user had to select the Quran verses to display during the ritual and specify which Salah to perform\(^\text{19}\).

The user interaction with the eRug, during Salah, was identical to the traditional rug. The user stands at one end of the eRug and performs the ritual. The selected verses were displayed automatically, page by page. The user could interrupt the page displaying at any time by moving to the next step. When the user performed an error of omission, an icon, with a minus sign enclosed in red circle (Figure 4.4), was displayed on lower part of the screen indicating to the user that a step was missing. An icon stylized image of a person bowing with a plus sign was used to indicate errors of commission (see Figure 4.4). The images were chosen so that the user can easily identify the error performed and correct it appropriately. The icons were selected because they are similar to icons used in desktop environments in popular operating systems, hence would be familiar to user.

Due to concerns that users might be distracted by the existence of the LCD, the display operated in one of two modes: scripture mode and camouflage mode. The scripture mode was active when the user is in the standing posture. The interface changed to the camouflage mode once the user was no longer in a standing posture. In the camouflage mode, the interface displayed a scan of the fabric that was cut from the prayer rug.

\(^{19}\) In addition to the five mandatory Salah, there are optional Salah that some users might want to perform.
Religious Opinion of Iteration 0

Since the religious scholar’s opinion of the prototype was crucial for general user acceptance, the scholar was contacted first. The religious scholar objected to three features in iteration 0; having the screen embedded inside the eRug, the LEDs panels along the sides and the error notification mechanism. With the LCD screen embedded in the prayer rug, the user could potentially step over the scripture with her body while performing different postures – which was considered disrespectful of the scripture. A second reason was that Muslims were instructed to lower their gaze towards the ground\textsuperscript{20} while praying and the screen location will force users to drop their sight further back from where they should be looking.

The objection to the LEDs was even more subtle. The religious scholar objected to the blue LEDs. When they are off, this indicates that the user did not pray yet. Some users might pray to avoid criticism that they did not perform the ritual and hence it would the fear of criticism by others that derives them to pray and not the actual desire to perform the ritual. The scholar described it as “a design that might encourage arrogance and

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\textsuperscript{20} Tradition teaches that during Salah one’s gaze should be approximately at 45 degrees angle towards the ground as a sign of humility.
The scholar asked that such information should be confidential and not publicly displayed. Another reason behind the objection was that the scholar feared that having a scale-like progressive indicator could encourage adherents to postpone prayer until the last minute. Although it is permissible to conduct the prayer at any time during the allocated interval, praying immediately at the beginning of the time interval is more recommended than postponing it.

Regarding the error notification mechanism, the scholar asked to find an alternative mechanism to displaying an icon on the screen since it was too distracting to the user. In addition, the Islamic ruling regarding how to notify an individual who was performing a prayer and committed an error was to alert the person to the fact that she committed an error but not to talk to the person directly. “Displaying an icon resembles talking to the person directly, plus the screen should not display anything but the scripture during prayer”, the scholar commented.

Regarding the camouflage mode, the scholar objected that it is still something to look at and recommended to switch off the LCD completely when there is no scripture being displayed.

The scholar also suggested supporting the detection of two other types of errors: 1) performing prayer too quickly: the adherent was supposed to perform the prayer at a slow pace “to show respect for God”, 2) excessive movement during prayer: the adherent was supposed to be in a calm posture and his movements should be minimal.

Evaluation of Iteration 0

Since the issues identified by the scholar required a major revision, only an evaluation of the posture detection mechanism was conducted for this iteration. Six non-Muslim
participants were recruited from the University of Toronto student community. Participants were unpaid and were informed they could withdraw at any time during the trial. Each trial consisted of the participant performing the prayer postures – without actually being in prayer. A second LCD was used to display a video recording of a Muslim performing the prayer during the trial. Participants were asked to reproduce the postures they saw in the video. The system was capable of detecting the current user posture with a success ratio of 60%\(^{21}\). False positives occurred because of the low resolution of the sensors combined with the variety in users’ height and body configuration. Since 60% was an unacceptable ratio, an alternative sensing mechanism was needed.

4.2.2 Iteration 1: eRug – Rubber Prototype

*Iteration 1 Hardware*

The second prototype had four goals; to address the scholar concerns, to increase the success ratio of detecting user postures – regardless of the user’s body configuration, to develop a more comfortable rug for use in experimental evaluation, and to detect the errors requested by the scholar.

The screen was removed from the flat panel and placed in a front compartment – slanted at a 45 degree angle to enable easy viewing (Figure 4.5). The LED panels were also removed and replaced by a software module which displays the prayer time and another password-protected module which tracks whether the user already performed the prayer or not. The screen had a touch sensitive surface which enabled the user to interact with

\(^{21}\) The software was modified to print the name of each posture as it is recognized and output compared against actual steps performed.
the eRug software using the on-screen keyboard. In case of error, instead of displaying an icon, miniature disc motors were embedded in the middle of the eRug and produced a vibration which acted as an ambient display. Jones and Sarter (2008) reviewed various works in tactile sensing and showed that optimal sensitivity for detecting vibration is between 150 and 300Hz for all body sites. The amplitude for detecting vibration at any given frequency does, however, vary considerably over the body, with the lowest thresholds (i.e., highest sensitivity) being measured on the fingertips (200Hz) while other body parts are less sensitive. During Salah, different body parts will be touching the eRug. For example, in the kneeling step; forehead, hands including fingertips, toes, and knees will be touching the eRug, while in the standing step; only the feet will be touching. Because the disc motor was sandwiched between the eRug rubber layers – which absorbed some of the vibration – experimentation had to be done to determine the appropriate vibration interval and pattern. A vibration of two seconds (250Hz) followed by a silence of two seconds and next another vibration of two seconds was deemed the most appropriate. Using tactile feedback may be considered less intrusive and could

![Figure 4.5: eRug 1.0 rubber prototype.](image)
satisfy the scholar requirement for an indirect notification mechanism.

While wood was chosen for iteration 0 due to the ease of construction, a softer material was selected for this next iteration. Rubber mats being flexible and strong enough to hold the user weight was chosen. Three rubber layers were put together to sandwich the sensors and the vibrating disc-motors. A top layer, which the user performs the prayer on, a middle layer containing the sensors and a bottom layer through which the sensors’ connectivity wires were passed (Figure 4.6a). The three touch sensors were replaced by 17 force sensors to increase the resolution and attempt to detect the errors requested by the scholar (Figure 4.6b). The force sensors were strategically located where the user’s feet, arms, knees, head and hands would touch the mat in various steps. Each force sensor was able to detect up to 1.5 kgf. The force sensors have a narrow point of contact, which could have caused discomfort to the user if she directly interacted with the sensor. To solve this problem, the force sensors were embedded inside the middle layer. Small, circular shaped rubber pads were glued to the back of the top layer and placed to press on the force sensors if depressed (Figures 4.6c & 4.6d). As the user performs various steps, she would be pressing on the top layer which in turn moves underlying pads down few millimeters exerting force on the force sensor’s head. The weight of the top rubber layer combined with the pads was considered in a calibration process to avoid false positives and negatives. Since the LabJack unit did not have enough communication ports to support the number of sensors used in this iteration, it was replaced by two Phidgets interface kit PCBs (Greenberg & Fitchett, 2001). The Phidgets boards were connected to the laptop and placed in the front compartment.
Software

The software from iteration 0 was modified to communicate with the Phidgets kit – instead of the LabJack – to sample the force and infrared sensors, and to control the vibrating disc motors. To enhance posture detection, several body type configurations were defined in the software based on height and weight. Experimentation with the eRug showed that using three heights (less than 170cm, between 170 and 180cm, greater than 180cm) and two weights (less than 80kg, greater than 80kg) produced adequate results. The user was required to select the appropriate body type as part of the setup. To detect a posture, the software used a finite state machine (Figure 4.7) combined with a predetermined sensors-signature matrix for each prayer posture and body type. The
software was also modified to detect praying too fast and performing excessive movement during prayer. To detect excessive movements, the readings from the various sensors were continuously cached during a two second window and the sensor readings were inspected to determine how many times the readings changed from maximum and minimum values. If the same sensor readings jumped between maximum and minimum more than three times in the two second window, then the user must have been moving excessively. To detect praying too fast, the amount of time it takes to execute a step – as described by the prophetic tradition (AlBukhari, 846/2002, #724); using a slow pace but not an animated one – was stored in the software. If more than two steps were performed hastily, that meant praying too fast.

![Figure 4.7: Muslim daily prayer represented using a state machine.](image)

**Interaction**

The interaction followed the same approach to that of iteration 0. The only exception was the feedback mechanism which used vibration to inform the user of the existence of an error. The error itself was not revealed to the user during prayer as per the scholar’s position. After prayer, the user could check the error log to find which error was performed.
Evaluation of Iteration 1

An informal evaluation was conducted to solicit user feedback, and investigate how accurate the prototype detects the users’ postures. Eight participants were recruited – one representing each body type category. All the participants were recruited from the University of Toronto graduate student community. Prior to the trials, participants were asked about which parts and pages of the Quran they memorized and used. A set of Quran pages was selected which none of the participants had memorized to avoid introducing a bias. Those pages were displayed during prayer for the participants to read. During the trial, each participant was asked to conduct two prayers, each of two rakaas. Next, participants were asked to provide feedback in the form of answers to open ended questions (Appendix C) regarding the eRug design. On average, each participant spent eight minutes praying. No errors of commission or omission were made.

Participants input revealed several issues with the design. Four participants commented on the rubber as being initially comfortable, but after a short duration, their feet would sink in, creating an awkward feeling. One participant, who had a history of back-related health problems, reported discomfort from standing still on the rubber during the standing step. Three participants mentioned that when they made the prostration step, they smelled the rubber odour. Two participants mentioned that the font used on the display was too small.

With 17 sensors, the success ratio for detecting user postures increased to 76%. However, a technical issue was uncovered with the design; participants do not perform each step using the right posture all the time and hence the individualized calibration did not

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22 A raka is the sequence of steps including: standing, bowing, and kneeling twice.
23 Given the short duration of the trial, it was not expected that participants would perform errors.
prevent false negatives. All the participants made postural errors though none of them recognized this.

On the positive side, all users reported that it was a very satisfying and emotional experience to use verses from the Quran, which they do not memorize, during prayer. Three participants were very impressed with the prototype concept to the extent that they expressed interest in owning one, if it is made available as a commercial product, because they believed it would have helped with them with enhancing the quality of their prayer.

The positive input from participants and the scholar about iteration 1 became a motivation for creating a realistic prototype of the eRug. Creating such a prototype would furnish the way for more formal objective and subjective evaluations which were needed for verifying constraint 224 as specified by the scholar.

4.2.3 Iteration 2: eRug – Peripheral Device

*Iteration 2 Hardware*

Instead of a rubber mat, a 3-layer circuit on thin flexible plastic sheets was developed. The top layer (Figure 4.8a) had a printed schematic of 29 active regions for the user to press. The middle layer (Figure 4.8b) was made of insulating foam with holes to enable the connection of each top layer button with the corresponding one on the bottom layer. The bottom layer (Figure 4.8c) acted as the electrical ground for the top layer and had a corresponding button pattern. The buttons’ locations and sizes were laid out to detect the steps and postures in prayer.

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24 Ritual quality constraint; any form of interface should not degrade the quality of prayer.
Figure 4.8: eRug Iteration 2 design. (a) Ground circuit - bottom layer. (b) Insulator foam – intermediate layer. (c) Active circuit - top layer. (d) Assembled eRug.
Conductive ink and silver were used to imprint the circuit on the top and bottom sheets. Ink, an inexpensive material, typically carbon mixed with copper, was used also to make the buttons. Silver was used to construct the electrical buses that carried the signals produced from the button activation to the controller board. The amount of ink used was checked against the interference limits within the circuit. When the user stood or sat on one of the buttons, his weight caused the top layer to touch the bottom layer – hence, closing the circuit for that button. Each button was connected directly to two peripheral circuit boards which were, in turn, connected to a microcontroller board through a serial interface. The entire circuit was controlled by a PIC16F877 microcontroller with 44 pins (Figure 4.9). PIC16F877 was chosen so that the 29 eRug buttons did not need to be scanned to register a reading.

![Figure 4.9: eRug iteration 2 controller circuit schematic.](image)

Due to this arrangement of the buttons, multiple closures could be detected and processes without concern about n-key lockout. The buttons were driven from the 5V supply. Upon activation a button would supply a logic 1 to the microcontroller input pins. The
microcontroller pin was held low by a resistor network to avoid false button captures. The rug buttons produced around 2K Ohm when closed. As a result the potential at the microcontroller pin sensed as logic 1 was around 3.3V. This configuration of sensing the buttons provided a sensing range up to 10K to register a positive activation. A set of capacitors were connected from the microcontroller pin to ground to eliminate any high frequency noise that may occur from electrostatic discharges from the human body. It also served to eliminate false button closure indications. A BC817 transistor allowed the vibration motors to be turned on/off on demand by the microcontroller while a freewheeling diode protected the transistor from inductive surges arising from the motor. Instead of the infrared sensors in earlier versions, a more accurate ultrasonic sensor, the Devantech SRF05 Ultrasonic Ranger (Figure 4.10) was used as a proximity sensor. This product was a sonar transmitter and receiver and microcontroller combined on a PCB. When the SRF05 input received a pulse, an ultra-sonic ping was sent from the transmitter. The device then waits for an echo and the distance from an object could be determined by measuring the time it takes to receive a response. The range can be set in steps of about 43mm, or 1.68 inches, detecting objects up to few meters away. The sonar sensor was strategically located in the middle in a transparent dome to detect the bowing step. The microcontroller sends a start pulse to the sonar sensor which then reads the

Figure 4.10: Devantech ultrasonic rangefinder.
distance to the nearest object in its line of sight and returns the echo distance as a pulse width proportional to the time of flight. To protect the circuits, the plastic sheets were enclosed in a thick plastic and attached from the sides using adhesive tape (Figure 4.11).

![Figure 4.11: eRug iteration 2.](image)

**Software**

The software for iteration 2 consisted of two components: a C program (Appendix D) that runs on the microchip PIC16F877 and a Java program that runs on a connected PC. The C program continuously samples the connected hardware circuit and communicates read data as packets to connected PC. The Java program implemented the higher level logic of detecting errors and display the Quran. The detection of postural errors was added to the Java program. Although postural errors do not invalidate Salah, it is religiously recommended to avoid them (AlAlbaani, 2005). The 29 buttons enables the software to detect six postural errors – increasing the total number of detectable errors to ten. The postural errors are: 1) putting hands close to head in prostration, 2) putting knees on the ground first before the hands when prostration, 3) collapsing back during prostration, 4)
arms touching ground when prostration, 5) raising feet off ground during prostration, and 6) feet not touching while sitting.

Using the vibration disc motor inside with flexible plastic sheets posed a challenge because the user sensing of the vibration was dependent on the type of floor the eRug was on. Fabrics (e.g. carpets) absorbed much of the vibration while wood, ceramics and marble transferred the vibration to the user body. This was not issue in the previous version because the eRug was made of rubber sheets which the vibration traveled within before reaching floor. To handle this issue, the user was given the option to select from three vibration levels – low (200Hz), medium (240Hz), and high (280Hz). Since postural errors do not invalidate the prayer, the user was given the option to disable their detection via a setup screen (Figure 4.12).

![Digital Prayer Rug Setup](image)

**Figure 4.12: Screen capture of eRug iteration 2 setup interface.**
To satisfy requirement 7\textsuperscript{25}, the software was modified to enable the user to read the whole Quran\textsuperscript{26} over a number of days by allocating a specific number of pages to be read during in each prayer. To satisfy requirement 8\textsuperscript{27}, a feature was added to display optional supplications from tradition, before and after prayer.

*Interaction*

The interaction followed the same approach to that of iteration 1. The only exception was that a connection between the eRug and a laptop was required. The laptop was then used to setup the eRug before prayer and to display the Quran pages.

*Religious Opinion of Iteration 2*

Since the eRug’s form was not expected to change further, the scholar was contacted for a formal religious opinion of the eRug. The scholar produced a religious opinion (fatwa\textsuperscript{28}) clarifying the suitability of the two new features in the eRug which separates it from a traditional prayer rug, namely: having a display to read Quran from during Salah and using vibration to alert the user to errors.

In regard to read Quran from text, instead of recalling it from memory, the scholar listed the opinions of earlier scholars, starting from the era of the prophet Mohamed (640 AD), followed by the views of prominent religious scholars in chronological order till present time. The scholar then noted that the opinion that carrying the Quran during Salah is not permissible is based on the argument that during Salah, a Muslim is not supposed to be engaged in any other work or activity. Carrying the Quran and flipping its pages represents a form of work, hence it was deemed inappropriate. Since the eRug neither

\textsuperscript{25} Requirement 7: provide customization to the prayer experience.
\textsuperscript{26} Quran has 624 pages.
\textsuperscript{27} Requirement 8: support pre-prayer and post-prayer supplication.
\textsuperscript{28} Appendix B contains a scan of the fatwa (in Arabic)
requires the user to carry the text nor flip the pages, then the underlying reason behind the prohibition is not applicable and it is permissible to read from the screen. The scholar excluded from his opinion two cases of 1) group mandatory prayer where there is an adult Muslim in the group who memorizes the Quran, or significant part thereof. In this case, that person must lead the Salah and perform it without reading from the screen, and 2) solo mandatory prayer where the individual is an adult Muslim and memorizes significant part of the Quran. In this case as well, that person must perform the Salah without reading from the screen. The rationale behind the exclusion is that Salah has been prescribed to have the Quran recalled from memory and if that ruling can be upheld, then it should be respected and followed. In all other cases, namely; 1) group mandatory Salah where there is no individual in the group who memorizes enough of the Quran, 2) group optional Salah (e.g. Tarweeh Salah in the month of Ramadan), 3) solo mandatory Salah where the individual does not memorize enough of the Quran, 4) solo optional Salah, 5) solo mandatory and optional Salah performed by a Muslim with cognitive challenges, and 6) solo mandatory and optional Salah performed by a Muslim child; the user is allowed to read the Quran from the screen.

Regarding the use of vibration to notify the user of errors, the scholar noted that it is permitted for the following cases: 1) solo mandatory Salah, and 2) solo optional Salah. In the case of the group Salah, it should not be used since it is the duty of the other Muslims, behind the prayer leader, to notify the leader that he committed an error.

Having confirmed the suitability of the eRug from a religious viewpoint, an evaluation of the features was launched as described below.
Evaluation of Iteration 2

Two separate studies were conducted to evaluate iteration 2. The first study was to test the ability of the new design to detect users’ postures. Using a similar protocol to that used in iteration 1, eight non-Muslim participants were recruited from the University of Toronto student community – each falling in one of the six previously designated body types. Participants were unpaid and were informed they could withdraw at any time during the trial. Each trial consisted of the participant performing the prayer postures – without actually being in prayer. A second LCD was used to display a video recording of a Muslim performing the prayer during the trial. Participants were asked to reproduce the postures they saw in the video. The system was capable of accurately detecting all the user postures\(^{29}\), and without using body type configuration.

After verifying iteration 2 functionality, a longitudinal study was planned to evaluate the long term impact of the eRug on the user. The study plan was to construct and validate a questionnaire based on flow theory\(^{30}\). The questionnaire was going be administrated twice before and after a period of four months during which the participants use the eRug. Comparing the scores of participants’ pre and post study was intended to examine user experience over a longer period to ensure that any novelty effect would be eliminated.

Twelve participants were recruited from local mosques in Toronto through advertisements. Participants were not paid and all were working professional males (\(M\) (age) = 30.75 yrs, \(SD = 3.3\)). Participants were told that they could withdraw at any time

\(^{29}\) The software was modified to print the name of each posture as it is recognized and output compared against actual steps performed.

\(^{30}\) Chapter Five is dedicated to the eRug evaluation. Section 5.7.2 provides an overview of the flow theory. Section 5.7.5 details the designed questionnaire. Section 5.8 contains a description of a successful longitudinal study.
during the study. Every two weeks, the participants were contacted via phone for follow up. Each participant was given an eRug to use in prayer.

In the first two weeks, three participants withdrew from the study. The main reason behind withdrawal was that it is inconvenient to use the eRug in the workplace. Normally, each of those participants kept a traditional prayer rug in their office. When the prayer interval arrives, they performed the prayer within few minutes. The eRug required a special setup with every usage, primarily to place an LCD (connected to a desktop computer) or a laptop in front of the eRug on the floor level. This process took a significant amount of time compared to the time it took to perform the prayer on a traditional prayer rug. Another reason cited by participants was that interacting with the setup of the eRug interface was awkward. The setup required a keyboard or a mouse to operate while the user is supposed to be standing on the other end of the eRug and distant from her desk — where a mouse or keyboard are located. For those users who used laptops, it was even more awkward since they had to sit on the eRug, run the setup, and then perform Salah. Within five weeks, four more participants withdrew from the study for the same reasons.

Consequently, the study was canceled due to the drop in the number of participants. The withdrawal of participants from the longitudinal study showed that the eRug needed to be an independent digital device with its own microcontroller and LCD screen and that a different interaction mechanism was required to replace the keyboard and mouse.

4.2.4 Iteration 3: eRug – Independent Device

Hardware
A second board was designed and built for the purpose of converting iteration 2 to an
independent device. The new board was driven by an Atmel microprocessor, run by Linux OS and used an enclosed 15” LCD screen. Appendix E has a detailed description of the embedded system hardware and software implementation. Figure 4.13 shows the eRug assembled with screen\textsuperscript{31}. The metal holder shown in Figure 4.13 is not part of the eRug. Instead, it was left for the user to position the LCD as deemed comfortable.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{eRug_iteration_3.png}
\caption{eRug iteration 3.}
\end{figure}

\textit{Application Software and Interaction}

Figures 4.14a and 4.14b show the menus that the user must go through to select which type of Salah she would like to perform. Figure 4.14a is the first screen the user sees when she switches on the device. Once the user triggers Perform Prayer option, the next screen to be displayed is Figure 4.14b which lists the different Salah rituals that could be performed during the day; the mandatory as well as the optional ones. The last choice in this menu (not shown in Figure 4.14b) is Go Back option to return to the starting screen (Figure 4.14a). Once the user selects a prayer, an intermediate blank screen is displayed for two seconds and then the display of scripture starts.

\textsuperscript{31} Controller board not shown as it was mounted behind.
Figures 4.14c, 4.14d, 4.14e and 4.14f display the menus the user must go through to adjust the vibration level associated with a specific type of error. The user would have to select Error Detection Setup option from the first screen (Figure 4.14a), and then the user selects either making a onetime change or making a change that will apply to all other following prayers. Next, the user selects whether the change applies to mandatory, optional or both types of prayer. The vibration change screen (Figure 4.14f) utilizes transparency to display a vertical slide bar which the user can traverse and select from using the same hand gestures.
Iteration 2’s evaluation showed that using a keyboard and mouse to interact with the eRug was awkward. Hence, a different interaction technique was needed. Such mechanism had to take into consideration that the user will be standing at one end of the eRug – away from the computer display. One alternative was using a subset of the 29 buttons in the eRug to create a foot-based interface. In such an interface, five buttons would be chosen to act as left-arrow, right-arrow, up-arrow, down-arrow, and enter buttons. The user would navigate through the interface by tapping on the appropriate buttons. Though feasible, this type of interaction is only suitable for simple interfaces with few options. However, the eRug interface had many options and settings, and a foot-based interface was deemed too slow for this application. Another alternative was using a body mounted wireless hardware, such as a wireless mouse. However, this required the user carrying the additional hardware wherever he goes. One of the advantages of the eRug is that it is a single-unit portable contained device. Adding additional hardware creates a burden on the user and losing that hardware renders the device unusable. A third alternative was to use a hand gesture interface – which required a camera to detect the gestures. Privacy concerns made such an option unfeasible. An alternative to a camera
was thought in the eRug’s sonar sensor. A hand gesture interaction technique and a menu
were developed, taking advantage of the sonar ability to detect objects in its field of view.
The menu (Figure 4.15a) scrolls only vertically and has two arrows at the top and at the
bottom which inform the user there are more options to be revealed. When an item in the
menu is selected, a black horizontal highlight is displayed on that item. The user interacts
with the system by placing his hand on top of the sonar. The user scrolls in the menu up
by moving his hand slowly up wards and scrolls down by moving his hand slowly down
(Figure 4.15b). The highlighting bar scrolls in the vertical menu accordingly. To trigger
an activation of a menu item, the user positions his hand on top of the sonar and moves it
quickly up and down twice.

Using a sonar sensor in detecting a gesture has several advantages over using a camera.
Sonar is indifferent to lighting conditions; hence it could be used indoors and in outdoors.
Cameras on the other hand only work in constrained lighting conditions, since image
segmentation\(^{32}\) requires a relatively clear distinction between the object to be detected (in
this case the hand) and background. In addition, sonar is a more economical alternative
compared to a camera. The sonar being placed in the middle of the eRug made it suitable
for such an interaction. The user would be standing in the side where she would stand to
start prayer, extend her hand over the sonar, make the selection and next start prayer
without having to move closer to the LCD\(^{33}\).

\(^{32}\) Image segmentation is a first and critical step in computer vision algorithms and it involves the detection
of boundaries of the object of concern.
\(^{33}\) Section 5.8 details a longitudinal study which included a subjective evaluation of this interaction
technique.
4.2.5 Conclusions

In this chapter, the eRug design iterations were presented. Four versions of the eRug have been developed in an iterative design process during which the input from the scholar and from users where solicited. Version 0 was a wood prototype with three touch sensors and three infrared sensors, and LEDs were used for displaying prayer interval information. Version 1 was made of rubber with 17 force sensors, two infrared sensors and a vibrating disc motor for user notification. Version 3 was a peripheral device to be connected to PC via serial port, with 29 buttons printed on flexible sheets and a sonar sensor. Version 3 enhanced version 2 by transforming it to an independent digital device. Introduced enhancements were either to satisfy a religious requirement or based on feedback from users while actually trying to use the eRug in a real life scenario. The final form of the eRug is a portable, light and independent digital device with its own microprocessor, storage and LCD. Version 3 of the eRug satisfies requirements 1 to 8 identified in Chapter 2, namely; to notify the user of prayer time and religious events, track performance of prayer, enable access to religious scripture during prayer, use interaction techniques that will not add to the ritual, assist in correcting errors, provide full control to
the user, provide customization to the prayer experience, and support pre and post prayer supplication.

Requirements 1 to 8 are resolved mostly through technical solutions, interface design, user customization features, and setup features. Requirement 9 which is to identify the direction of Mecca is still not yet supported. The following chapter is dedicated to assessing whether requirement 10 – to avoid degrading the quality of prayer – is satisfied.
Chapter 5

Evaluation of the Electronic Prayer Rug

5.1 Evaluation Strategy

A major concern the scholar raised in iteration 0 feedback was that in order for the eRug to be religiously acceptable, evidence is needed to demonstrate that it will not degrade prayer quality. Given the significance of Salah in a Muslim’s daily life, this requirement became a critical factor for the success of the eRug – regardless of any other feature it might offer to the user. However, proving the effectiveness of a device or an interface supporting a religious ritual is a challenging task for the following reasons:

Nature of spiritual experience
There is no adequate scientific model to capture all the dimensions of the spiritual experience. Using modern technologies, only the outward manifestations of the spiritual experience – and not the experience itself – can be recorded. Asking users to subjectively evaluate their own performance is insufficient since humans cannot accurately report such experiences.

Rarity of Errors
Although practitioners perform errors during rituals, the frequency of errors is small in magnitude. The slow pace of the ritual and the continuous practice – since childhood – contribute to decreasing the error frequency. Hence, unlike secular tasks, errors count does not represent a valid measure for evaluating effectiveness.

Execution Time is Irrelevant
In a secular task, execution time is often considered the standard for measuring the
efficiency of an interface (Reynolds & Picard, 2001). In executing a religious ritual, being fast or even efficient is often not recommended.

Concern over Observer-expectancy Effect

Religious rituals are very personal experiences. Any attempt to monitor, evaluate, or quantify the performance raises concerns related to the Hawthorn effect (Landsberger, 1958), which is the possible interference of the measurement procedure on the process being measured.

Concern over Novelty-Effect Impact

Clark and Sugrue (1988) in a review of educational tools noted that novelty effect\(^\text{34}\) causes \(\sim 30\%\) increase in standard deviation, which decays to small level after eight weeks. Given that the impact of religious rituals are much less understood than that of secular tasks, it is not clear after how long will a tool for a religious ritual show novelty effect and what is the impact on standard deviation.

Concern over Individual Differences

Practitioners of religious rituals can be classified according to three broad categories; those who rarely practice, average practitioners who practice often, and finally the experts. It is not clear how will a participant’s expertise will correlate with the recorded impact of using a new digital interface in a ritual. Lutz et al. (2003) and Ekman et al. (Ekman, Campos, Davidson, & De Waass, 2003) have shown that meditation and spiritual experiences may induce long-term neural changes among experts\(^\text{35}\) characterized by unprecedented display of mental control. Hence, even if a digital interface provides

\(^{34}\) The tendency for performance to initially improve when new technology is used.

\(^{35}\) Although these two studies focused on Buddhist monks, yet religious rituals have many shared brain wave patterns (discussed in section 5.4.3). These similarities justify the generalization of Lutz et al. (2003) and Ekman et al. (2003) observation to other religions.
new functionality, the recorded impact on an expert’s performance might be minimal. Similarly, within the average user category, several subcategories could be identified according to; consistency of ritual performance, conviction in the religion, and religious knowledge. The selection of participants for an experiment involving a religious ritual requires careful consideration of the different categories of users and the consequence of mixing participants from those categories.

*Concern over Response Accuracy*

Asking practitioners of a ritual to determine the quality of their performance raises concerns over the validity of their answers. Data contamination by some participants who decide not to disclose their actual performance neither can be avoided nor easily detected. Given the complexities involved in conducting an evaluation of a tool supporting religious rituals; two independent studies were planned. The first study involved physiological evaluation of the user while performing Salah on the eRug. Since the number of errors and execution time are inappropriate measures, resorting to indirect means to measure user performance became essential. Physiological measurement, as it allows for a real-time assessment of biological activities, would be used to capture the outward cognitive manifestations of the spiritual experience. In addition, physiological techniques were potentially much less intrusive than self-reporting methods, such as a verbal protocol.

The second study involves a longitudinal evaluation of the impact of using the eRug. Since the novelty-effect of using a tool for religious ritual is unclear, the study was planned for four month period (similar to the aborted study for iteration 2), to attempt to overcome any such effect. During the four months, participants would use the eRug in
their daily prayers. Observer-effect would not be factor in the second study, where participants were using the eRug in a real life scenario without monitoring. This study relied on responses to questionnaires rather than real-time physiological measures.

Since selecting participants for both studies was a challenge, given the variation among participants, a questionnaire was used to pre-qualify participants. Section 5.4 is dedicated to the issue of selecting participants.

If the two studies yielded similar results, then and only then, one can conclude with some confidence about the impact of the eRug on prayer quality. Yielding similar results, i.e. what the participants report in the longitudinal study agrees with what are recorded using physiological measures, means that neither the Hawthorn effect, the novelty effect, nor participants misrepresentation of prayer performance are responsible for those results. Thus; 1) the impact of the eRug is shown objectively, and 2) that effect is permanent – since it is validated for an extended period of time.

Before conducting the eRug evaluation studies, an extensive search in physiological and psychology literature was conducted to examine previous research on Salah and measuring prayer or mediation. Although, numerous studies confirmed that Salah has an effect on practitioners, none of these studies reported a measure that could be used to quantify the effect of the eRug. Consequently, a first study was required to determine the suitability of the measure used in the eRug evaluation. The next section provides an overview of previous studies on Salah – which provides important contextual information for the experiments reported in the following sections.
5.2 Previous Studies of Salah

Salah’s effect on the practitioner has been noted and studied by Muslim scientists since the ninth century. Alrazi (2010), Avicenna (2010), and IbnAlnafis (2010) – famous figures in the history of medicine – believed that Salah has a positive physical, emotional and spiritual effect. Muslim scholars have advocated the practice of Salah to the extent that they often prescribed it combined with a diet of fresh foods and herbal medicine as a treatment to ailments (e.g. AlJawziyyah, 1330/1999; AlJawziyyah, 1340/2004). However, their opinion was based on experience and direct observation rather than empirical evidence.

In recent years, researchers began evaluating the impact of Salah using more formal and rigorous protocols. The reader is referred to section 1.1 for a review of such studies. Several scientists have proposed explanations regarding the impact of Salah. Three factors seem to contribute to the perceived positive effect: performing the physical movement, invoking energy activation points in the body using the sense of touch, and disconnecting from the surrounding social context and concentrating in the recalled Quran text.

Altharshi (1992) investigated the relationship between Salah and physical benefits. He noted that a person who prays the five daily Salahs performs 280 varied body movements, including standing, bowing 36 times, prostrating 72 times, deep breathing, neck movements, raising the hands, moving the digits, and sitting. This can be considered as light exercise, which is repeated five times days for the five daily rituals. Al-Tharshi argued that such exercise not only has physical benefits but also has psychological and spiritual benefits. Al-Tharshi observation of the Salah being a mini exercise was
confirmed by Reza et al. (Reza, Urakami, & Mano, 2002) who used a goniometer to measure the active range for joints that were involved in a geriatric and disabled patient’s rehabilitation program. The study findings show that various muscles are exercised during each Salah posture. The various movements enhance the blood flow throughout the body which in turn has a positive psychological effect on the patient. Several researchers have noted similar observations. For example, Syed (2010) postulated that in the case of Taraweeh Salah – a special Salah held in the month of Ramadan and lasts up to three hours – the positive feelings could be attributed to the physical movements. Syed explained that Salah postures cause the muscles to contract isometrically\(^{36}\) and isotonically\(^{37}\), resulting in a relative deficiency of oxygen and muscle nutrients. This deficiency simulates a reaction similar to that of physical exercise, hence reducing stress-related autonomic responses in healthy persons, and relieving anxiety and depression. Similarly, Beebani (2000) noted that the prostration\(^{38}\) is a unique position as this is the only position in which head becomes lower than the heart and blood flows towards the brain with full force whereas in all other positions, even when lying, brain is above the heart when it has to work against gravity to send blood to the brain.

The second factor involves the invocation of energy activation points in the body using the sense of touch. Burns (2001) noted that Salah’s effect is primarily due to the activation of energy points found in the human body. Salah postures seem to have corresponding yoga counterparts. Various Salah postures together activate all seven energy fields in the body – which is what yoga tries to achieve. For example, the position

\(^{36}\) Same length.
\(^{37}\) Same tension.
\(^{38}\) Illustrated in Figure 2.1e.
of bowing\textsuperscript{39} is very similar to the forward bend position in yoga. Bowing or Ruku stretches the muscles of the lower back, thighs, legs and calves, and allows blood to be pumped down into the upper torso. This position promotes a greater flow of blood into the upper regions of body – allowing mental toxins to be disposed (Burns, 2001). Burns believes that a person who activates all seven nerve pathways can remain well balanced emotionally, physically and spiritually.

Benson’s "relaxation response" could be a third explanation as to why Salah seem to have a positive effect. Benson et al. (Benson, Beary, & Carol, 1974) found that repetition of a prayer, or muscular activity coupled with passive disregard of intensive thoughts causes what he terms as a "relaxation response" that leads to the lowering of blood pressure and decreases in oxygen consumption and a reduction in heart and respiratory rates. The recitation of Quran verses and supplications, accompanied by the attempt to concentrate on the performance of Salah, could be causing a similar relaxation response.

Although the above quoted researchers used more rigorous techniques compared to ninth century scholars none has used physiological measures to confirm their field observations. None of these studies reported a measure that could be used to quantify the effect of the eRug.

In the following section, background information about physiological evaluation is presented with the goal of informing the reader of the possibilities, complexities and limitations of this type of measurement technique.

\textsuperscript{39} Illustrated in Figure 2.1c.
5.3 Physiological Evaluation

Physiological evaluation involves the measurements of biological signals produced by the human body (e.g., heart rate). Some of the more commonly measured physiological signals include:

1) galvanic skin response (GSR); measuring the electrical resistance of the skin,
2) blood volume pulse (BVP); measuring the phase change in blood volume with each heartbeat,
3) electromyography (EMG); the recording of the electrical activity produced by facial muscles,
4) electrocardiography (ECG/EKG); the capturing of the electrical activity of the heart over time by skin electrodes,
5) electroencephalography (EEG); the recording of electrical activity along the scalp produced by the firing of neurons within the brain,
6) magnetoencephalography (MEG), which involves mapping brain activity by recording magnetic fields produced by brain electrical currents, and lately
7) functional Magnetic Resonance Imaging (fMRI); which measures the change in blood flow related to neural activity in the brain.

The following section presents an overview of related HCI literature that has used physiological measures for assessing human performance.

5.3.1 Using Physiological Measures in HCI Evaluation

In recent years, HCI researchers have begun to consider physiological measurements in usability evaluation. Wilson and Sasse (2001) correlated the user’s GSR, HR and BVP
with the quality of video (five verses 25 frames per second) being watched, and calculated a user stress index based on that. Although users did not notice the change in frame rate, their physiological indicators showed that they were experiencing stress. Scheirer et al. (Scheirer, Fernandez, Klein, & Picard, 2002) utilized GSR and BVP data to train a hidden markov model to detect states of frustration. Ward and Marsden (2003) used GSR, HR, and BVP of the user to assess the quality of web page design. Zhai et al. (Zhai, Barreto, Chin, & Chao, 2005) used GSR and BVP to measure user stress. One limitation with using GSR, HR, or BVP is that different feelings produce similar responses, because these instruments really measure arousal (Mandryk & Inkpen, 2004), which in turn is associated with many conditions. Hence, researchers must be careful with using them and that is why it is often combined with other physiological measures. A more promising bodily response measure is the facial EMG, which is an electrical potential accompanying the contraction of muscle fibers. Subtle contractions of facial muscles during exposure to attitude-relevant stimuli, such as beliefs and experiences, appear to reveal underlying positive or negative states (Cacioppo & Petty, 1981). Hazlett (2006) used EMG to track the zygomaticus face muscle, which controls smiling, and the corrugators face muscle, which controls raising the eyebrow. Using a video game as a test bed, Hazlett’s study showed that the zygomaticus muscle EMG was found to be significantly greater during positive events as compared to negative. Similarly, the corrugator muscle EMG was found to be significantly greater during negative events. Studies by Mandryk el al. (Mandryk, Atkins, & Inkpen, 2006), Mahlke et al. (Mahlke, Ming, & Thüring, 2006) and Isbister el al. (Isbister, Höök, Sharp, & Laaksolahti, 2006) also demonstrated that positive valence can be measured during interactive experiences
with EMG, HR and GSR. Similarly, the corrugator muscle can measure negative valence during intense interactive experiences. One potential problem with EMG is that it only measures the muscular manifestation of user state. If a state does not have an associated muscular manifestation, or if two states have the same muscular manifestation, EMG cannot be used.

EEG is another type of physiological measure that focuses on recording the electrical activity in the brain. Several HCI researchers have used EEG to identify user emotions and mental states while interacting with an interface. Muter et al. (Muter, Furedy, Vincent, & Pelcowitz, 1993) was one of the earliest researchers to find that physiological measures can be regarded useful for usability evaluation. They used skin conductance, heart rate and EEG to determine if a system is user friendly or not. Musha et al. (Musha, Terasaki, Haque, & Ivanitsky, 1997) extracted cross-correlation coefficients between the EEG activity from different scalp locations, and computed an emotion matrix to transform corresponds with the four basic emotions; anger, sadness, joy, and relaxation. The authors do not mention how well their system performs. Bostanov (2003) analyzed event related potential (ERP)\textsuperscript{40} using wavelet-based techniques to identify affective states such as joy or woe. Chanel et al. (Chanel, Kronegg, Grandjean, & Pun, 2005) tried to recognize the arousal dimension of emotion from EEG and other physiological measures. The activity in specific EEG bands on specific locations on the scalp was used as features to describe the EEG data. Success rate of identifying arousal was around 60%. Horlings et al. (Horlings, Datcu, & Rothkrantz, 2008) built a database of EEG signals recorded while watching pictures to induce specific emotions. Next, he used neural networks to

\textsuperscript{40} An ERP is a time-locked positive or negative wave of specific duration that appears in a known scalp location as a response to external or internal events (Picton & Hillyard, 1988).
classify the data on two emotional dimensions; valence and arousal. Horlings et al. (2008) reached rates of 32% for recognizing the valence dimension and 37% for the arousal dimension. Grimes et al. (2008) used EEG to classify working memory load into one of eight categories: interruptibility, cognitive workload, task engagement, communication mediation, interpreting and predicting system response, surprise, satisfaction, and frustration. Each one of those eight categories has a unique brain waves signature that could be detected by EEG.

Although EEG is a promising technique due its ability to capture the electrical signal of the brain and thus it reveals more than other physiological indicators, it’s relatively low resolution means that one can only make broad localization assumptions (Evans & Abarbanel, 1999).

5.3.2 Physiological Measure for eRug Evaluation

While there have been different physiological indicators used to study the user state during performing a task, most of these measures were deemed inappropriate for the eRug. GSR and BVP seem to be useful as indicator of a change in the mental state – to identify a board state such as being at rest versus being under stress – rather than describing the mental state itself. If a particular type of spiritual experience reduces blood pressure, it is important to understand what the user actually experienced.

Brain indicators are likely more appropriate to studying the user state while performing a religious ritual. Brain indicators, which include EEG, MEG and fMRI, are classified according to their spatial and temporal resolutions among other factors. Table 5.1 shows the main differences. For eRug evaluation purposes, EEG was the most appropriate
because the user must perform physical movements, while MEG and fMRI are very sensitive to motion artifacts. In addition, EEG recording is a silent recording system which is important to avoid distracting the user while praying.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Spatial Resolution</th>
<th>Temporal Resolution</th>
<th>Motion Sensitivity</th>
<th>Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG</td>
<td>Low (~20 mm)</td>
<td>High (~1/1000 sec)</td>
<td>Low</td>
<td>Silent</td>
</tr>
<tr>
<td>MEG</td>
<td>High (~3 mm)</td>
<td>High (~1/1000 sec)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>fMRI</td>
<td>High (~3 mm)</td>
<td>Poor (~1/2 sec)</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

*Table 5.1: Comparison of brain physiological indicators.*

5.3.3 EEG

When brain cells, neurons, are activated, local current flows are produced. Brain electrical current consists mostly of ions that are pumped through channels in neuron membranes. Large populations of active neurons generate electrical activity recordable on the head surface. EEG is a medical imaging technique that reads scalp electrical activity generated by brain structures.

*Brain Specialization*

From an anatomical point of view, the brain contains areas of low-level and high-level functions as different brain areas are related to different functions of the brain (Figure 5.1). For example, the vision area is located at the back of the skull. When a user closes her eyes, the neuronal activity in the vision area is greatly diminished – as demonstrated by EEG recordings. Studies have shown that two or more brain areas could establish communication link to speed up the processing of stimuli. For example, watching a video employs the activation and synchronization of the vision and the auditory areas.
**EEG Apparatus**

An EEG apparatus is fundamentally a recording system consisting of electrodes with conductive media, amplifiers with filters, an A/D converter and a recording device (Figure 5.2a). The brain signal is measured by electrodes inserted into the conductive media which is placed in contact with the participant’s skull. Electrodes conduct voltage potentials as microvolt level signals over time, and carry them into amplifiers that magnify the signals approximately thousand times. Since a successful recording depends strongly on the electrodes’ ability to capture the brain electrical signal at the skull, electrodes are usually constructed from good conductive materials, such as gold or silver chloride. EEG electrodes must be sensitive enough to measure brain signals of 35 micro volts to 100 micro volts\(^4\). High impedance caused by electrode length and thickness can lead to distortions or noise which can be difficult to separate from an actual signal. Hence, electrode impedance is usually kept below 5k Ohms (American Society of Electroneurodiagnostic Technologists, 2000). The conductive paste contains large concentrations of electrolytes, and is placed on the participant’s head (Figure 5.2c) to

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\(^4\) Typical range recorded at the surface of the skull.
maintain an acceptable signal to noise ratio. Capturing an accurate picture of what happens inside the brain depends on the sampling rate which should be at least twice the maximum frequency of interest (Dumermuth & Molinari, 1987).

**EEG Montage**

Studies on simulated as well as real EEG data have suggested that electrodes should be placed at a minimum distance of 2-3 cm from each other to prevent distortions of the scalp potential distribution. This allows the identification of EEG waves from different functional areas in the brain (Srinivasan, Tucker, & Murias, 1998). Electrodes are placed in a layout that attempts to maximize the coverage of brain cerebrum. The most popular electrode layout is the 10-20 montage with 21 electrodes (Figure 5.3). The 10-20 is based...
on the relationship between the location of an electrode and the underlying area of cerebral cortex. When accurate localization of brain wave sources is required, a 10-10 montage with 64 or 128 electrodes is used instead. For the purpose of HCI research, the 10-20 montage is accurate enough to capture a snapshot of the brain activities. Electrodes are placed in specific positions in order to record the activity of particular regions of the brain. The electrodes are coded according to their position relative to the region of the underlying cerebral structures (O - occipital; P - parietal; C - central; F - frontal; FP - frontal pole; T - temporal; A - auricular). Each scalp electrode is located near certain brain centers. For example, F7 is located near the brain areas responsible for rational activities; Fz is located near intentional and motivational centers, F8 close to sources of emotional impulses (Kropotov, 2008). Cortices around C3, C4, and Cz locations are for sensory and motor functions. Locations near P3, P4, and Pz contribute to activity of perception and differentiation (Kropotov, 2008). T3 and T4 are located near auditory cortex, while memory functions are located near T5 and T6 (Kropotov, 2008). Primary visual areas can be found below points O1 and O2 (Kropotov, 2008).

Although the scalp electrodes may not accurately reflect specific areas of the cortex, as the exact location of the active sources is still an open problem due to limitations caused by the non-homogeneous properties of the skull and due to different orientations of the cortex sources, the data collected from an electrode above a specific area is considered an approximation of the neural activity in that area. For this thesis, I am not concerned about an absolute measure of brain activity but rather a relative one; change in neural activity from resting to prayer and back to resting in brain areas.

42 The "10" and "20" refer to the 10% or 20% inter-electrode distance.
**EEG Measurement**

Measured EEG signals always represent the potential difference between two electrodes, an active electrode and a reference electrode. It is important to choose an area that is relatively electrically neutral to the investigation being conducted to avoid introducing distortions in the recorded data. There are two approaches for selecting a reference; physical verses virtual, or reference free. The physical reference can be chosen as either Cz, ears or tip of the nose. Referencing to ears and Cz are predominant in the literature for 10-20 montage. Cz reference is advantageous when it is located in the middle between electrodes. Reference-free techniques do not suffer from problems associated with an actual physical reference since the reading of a single electrode is measured in-relation to the average or weighted average of all electrodes. The disadvantage is that reference-free techniques require relatively high numbers of electrodes for reliable estimates; 32 electrodes or above (Tyner, Knott, & Mayer, 1983). In the eRug studies, Cz will be used as the reference.

**EEG Analysis Methodology**

Each EEG electrode is recording a composite signal, containing embedded frequencies of up to 75 Hz. Figure 5.4 shows typical waveforms of a one second EEG segment containing data from one electrode. The x-axis is time in milliseconds (ms) while the y-
axis is micro volts (µV). The two major variables describing a signal are amplitude (height/magnitude) and frequency or how many times/sec the signal crosses 0 µV and goes from plus to minus. The greatest challenge in using EEG is to identify the right analysis technique. Fast fourier transformation (FFT), independent component analysis (ICA), principal component analysis, linear discriminate analysis, support vector machines, wavelets, neural networks, fuzzy logic, genetic algorithms, signal coherence, signal synchronization, and chaos theory have all been used to decompose the EEG signal to simpler comprehensible dimensions. Each of these techniques reveals interesting facts about the recorded data while concealing others. Studying the brain performance, during a task, for the first time challenges researchers due to the inability to predict beforehand which EEG changes is the signature associated with that task. In such a situation, researchers often use a trial-and-error approach to determine the most appropriate analysis methodology.

Since the task at hand is a religious ritual, related studies have been used as a guide regarding the best technique to use. There are three types of measures that together seem to provide the clearest picture of changes in the brain: power spectral analysis, coherence analysis, and left-right symmetry (Evans & Abarbanel, 1999). Spectral analysis reflects the intensity of the brain signal, coherence analysis identifies the regions in the brain which work together, while left-right symmetry shows whether the one of the two brain lobes is dominant or working together to accomplish the task.

Prior to performing any of these analyses, the EEG data must be filtered for interference artifacts because the raw EEG signal is virtually always contaminated by various sources.

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43 The reader is referred to Gottman (1981), and Sanei and Chambers (2007) for details of how each of those techniques is used in EEG analysis.
EEG Artifact Removal

There are two broad types of artifacts; non-biological and biological artifacts. Use of notch filters (50/60 Hz from power lines), proper subject grounding, and shielding of the recording system can greatly diminish the influence of non-biological artifacts. Biological artifacts derive from muscle and eye movements made by the participant. Normal eye movements are within the 1 to 1.5 Hz range, suggesting that their second-order harmonics, 2-3 Hz, are within the delta range of valid brain activity (Thakor & Tong, 2004). Muscle activity produce artifacts with frequency 25 Hz and above. Since these artifacts overlap in frequency and amplitude with the target brain signals, their removal is essential. However, due to frequency overlap, removing muscle artifacts through filtering can greatly distort real EEG signals. To remove biological artifacts, ICA is often used to separate the EEG signal into its sources. EEG recorded at scalp locations is a product of synchronized activity arising from localized populations of radially-oriented neurons. Volume conduction of neural activity through the scalp is largely

Figure 5.5: Independent component analysis simulation (a) Each source contributes to all electrodes (b) Separation of sources enables the removal of noise.
linear; therefore, EEG recordings obtained at an electrode sums currents in accordance with the linear superposition assumption undertaken in ICA (Roberts & Everson, 2001). Since the linear ICA model corresponds to an EEG model in which a number of scalp sensors capture mixtures of sources located in the brain (see Figure 5.5 for a simulation), applying ICA to EEG recordings enables reconstruction of the generating processes in the brain (Sanei & Chambers, 2007). Sources that represent artifacts are eliminated either manually or using automated means such as filters. Next, the signal is reconstructed again from the sources without artifacts. Analyzing the independent components requires an understanding of the possible artifacts and their characteristics. For example, the amplitude of eye blinks is greatest at the anterior electrodes, where it can be between 50 and 200 µV. If an eye blinks artifact exists, it will appear in one of the sources closer to the front of the head - since the vibration caused by the eye movement is stronger at the front of the head and weakens as it travels to the back of the head (American Society of Electroneurodiagnostic Technologists, 1999). Other types of artifacts, such as jaw movement, could appear anywhere but due to the nature of ICA, only a specific interval in one source will represent such movement (Tatum, 2007). By deleting that interval - the effect of the noise is removed.

**EEG Indicator 1: Spectral Analysis**

Spectral analyses are based on the notion that any oscillatory activity can be characterized by the sum of different sine waves with distinct frequencies and amplitude (see Figure 5.6 for a simulation). The goal of spectral analyses, thus, is to estimate the contribution of specific frequencies on the measured EEG signal. Early EEG analysis research used FFT to analyze the signal (Dumermuth & Fluhler, 1967). Mathematically,
the Fourier coefficients indicate the strength of the signal at a given frequency. One way of estimating the power spectrum of a signal is to find the discrete-time Fourier transform of the samples of the signal and take the magnitude squared of the result\textsuperscript{44}. However, because FFT suffers from large noise sensitivity, two alternative techniques – also based on Fourier transformation – are commonly used instead; wavelets and multitapers. Kemerait and Childers (1972) proposed using wavelets instead of FFT to analyze EEG signals. Similar to Fourier analysis, where a signal is decomposed into a series of sine and cosine functions, the wavelet is the sum over all time of a signal multiplied by scaled (a) and shifted (b) versions of the chosen wavelet basis function. The calculated

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Constituent Wave Frequency (Hz) & Power (W/Hz) \\
\hline
0.5 & 5.26 \\
1 & 14.10 \\
1.5 & 10.2 \\
\ldots & \ldots \\
\hline
\end{tabular}
\caption{Power of individual wave frequencies embedded in a composite signal from one electrode.}
\end{table}

\textsuperscript{44} This estimate is often called the periodogram.
coefficients, Wavelet(a,b), reflect the correlation between the original signal, and the wavelet basis function at specific scales, or frequencies, as a function of time. There are several families of wavelets, and although each has specific features that might enable certain applications, the final choice of the basis function is often made experimentally. A disadvantage of using wavelets is that it is computationally inefficient due to the overlap or correlation between the different wavelets (van Vugt, Sederberg, & Kahana, 2007). Multitapers, a more efficient technique was proposed by Mitra and Pesaran (1999). Multitapers are sets of functions that were designed to reduce overlapping between frequencies (Walden, Percival, & McCoy, 1998). An important distinction from wavelets is that the width of the function stays the same in absolute time across frequencies. In the multitaper method, the data is first are multiplied with special window functions, to prevent bleeding between frequencies. Next, a Fourier transform is performed, and the absolute square is taken of the resulting signal. For the eRug evaluation, multitaper was used to decompose the EEG signal.

Spectral analysis yields the power associated with every signal component yielding a tabular data set similar to exemplary Table 5.2. This data set needs to be grouped into five mutually exclusive frequency subsets: Delta; 0.5 to 4 Hz, Theta; 5 to 8 Hz, Alpha; 9 to 13 Hz, Beta; 14 to 24 Hz, and Gamma; above 25Hz. Neurophysiologists have discovered that each of those frequencies distinguishes a specific set of mental states. The state of consciousness of an individual may make one frequency range more pronounced than others. Following is a description of each of those frequencies:

45 Similar to a Fourier transform.
46 The window functions used are either slepian or discrete prolate spheroidal sequences functions.
47 For a detailed comparison between FFT, wavelets and multitapers, the reader is referred to Drongelen (2007) and Gottman (1981).
1) Delta waves; lie within the range of 0.5 to 4 Hz (Figure 5.7a), with variable amplitude, and are considered the slowest form of mental processing (Crespel & Gélisse, 2005). Delta waves have been associated with sleep (Dement & Kleitman, 1957), advanced meditators (Banquet, 1973), and infants (Hagne, 1972).

2) Theta waves: lie within the range of 5 to 8 Hz (Figure 5.7b), with an amplitude usually greater than 20 µV (Crespel & Gélisse, 2005). Theta has been associated with access to unconscious material, creative inspiration as well as meditation (Sanei & Chambers, 2007).

3) Alpha waves; lie between 9 and 13 Hz (Figure 5.7c), with a 30 µV - 50 µV amplitude (Crespel & Gélisse, 2005). Alpha waves have been thought to indicate a relaxed awareness (Sanei & Chambers, 2007). Alpha is the most prominent wave in the whole realm of brain activity, accounting for ~70% of EEG activity in an adult human brain (Sanei & Chambers, 2007).

4) Beta waves; lie between 14 and 24 Hz (Figure 5.7d), and usually has a low voltage between 5-30 µV (Crespel & Gélisse, 2005). Beta is the brain wave usually associated with active thinking, active attention, focusing on the outside world or solving concrete problems (Sanei & Chambers, 2007). Hence, beta waves appear when we think logically, solve problems, and confront external stimuli.

5) Gamma waves; lie within the range of 25 Hz (Figure 5.7e) and up (Crespel & Gélisse, 2005). It is thought that this band is involved in connecting distinct modular brain areas into coherent whole behaving together (Buzsáki, 2006). For example, during a memory involving sight and sound, visual and auditory areas must talk to each other. Gamma is theorized to carry the information (VonStein & Sarnthein, 2000). In general, Gamma
rhythms are involved with local high rates of processing in a relatively small cortical territory.

Figure 5.7: Brain waves. (a) Delta. (b) Theta. (c) Alpha. (d) Beta. (e) Gamma – from (Electroencephalography, 2011).

Since frequency ranges are more relevant to evaluating the user mental states in EEG, the power\textsuperscript{48} is summed for each band, yielding a table similar to Table 5.3.

\textsuperscript{48} The term power describes how the energy, or variance, of a signal or a time series is distributed with frequency.
<table>
<thead>
<tr>
<th>Wave Type</th>
<th>$\sum$ Power (W/Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta (0.5 - 4 Hz)</td>
<td>5.5</td>
</tr>
<tr>
<td>Theta (5 - 8 Hz)</td>
<td>18.9</td>
</tr>
<tr>
<td>Alpha (9 - 13 Hz)</td>
<td>30.1</td>
</tr>
<tr>
<td>Beta (14 - 24 Hz)</td>
<td>22.3</td>
</tr>
<tr>
<td>Gamma (25 - 59 Hz)</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Table 5.3: Typical power of frequency bands embedded in a composite signal from one electrode.

Statistical Analysis of EEG Spectral Data

After removing artifacts; delta, theta, alpha, beta, gamma powers can be computed for every electrode, for each condition (Table 5.4). An ANOVA test followed by post hoc analyses are used to test the null hypothesis that all of the group means are equal and determine which groups are significantly different from each other. To do this requires a second post hoc step, which can be done with a variety of common procedures such as Tukey or Bonferroni post hoc analyses.

<table>
<thead>
<tr>
<th>Electrode 1</th>
<th>Participant 1</th>
<th>...</th>
<th>Participant N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode N</td>
<td>Participant 1</td>
<td>...</td>
<td>Participant N</td>
</tr>
</tbody>
</table>

Table 5.4: Electrode x participants x conditions power.

EEG Indicator 2: Coherence

Coherence is a measure of coordination between two brain locations, hence functional connectivity in the brain (Von der Malsburg, 1985). It shows the consistency of the analytical phase differences over a time interval and is measured using a squared
correlation coefficient (Otnes & Enochson, 1972; 1978). When the phase difference in successive time intervals is constant then coherence has the value one and when phase differences are random then coherence has the value zero. Mathematically, coherence between two waveforms \( x \) and \( y \) is calculated spectrally as (Kropotov, 2008):

\[
\gamma_{xy}^2(f) = \frac{G_{xy}^2(f)}{G_{xx}(f) G_{yy}(f)}
\]

where \( \gamma_{xy}(f) \) is the coherence on band \( f \), \( G_{xy}(f) \) is the mean cross-power density and \( G_{xx}(f) \) and \( G_{yy}(f) \) are the respective mean auto-power spectral densities. The computational procedure to obtain coherence involves first computing the power spectra for \( x \) and \( y \) and then computing the cross-spectra producing an average cos-spectrum \( r \) and quad-spectrum \( q \)\(^{49}\). Then, coherence can be calculated as follows (Kropotov, 2008):

\[
\gamma_{xy}^2(f) = \frac{\sum N (r_{xy} + iq_{xy})^2}{\sum N G_{xx} G_{yy}}
\]

One serious limitation of EEG coherence measures is contamination by volume conduction through the tissues separating sources and electrodes. This problem can be handled by applying a surface laplacian transformation to the data, to reduce the spatial scale of scalp potentials (Law, Nunez, & Wijesinghe, 1993; Nunez et al., 1991; Srinivasan et al., 1996). The surface laplacian is the second spatial derivative of the scalp potential in two surface coordinates tangent to the local scalp. Magnitude square coherence of \( x \) and \( y \) is typically computed using the Welch's averaged modified periodogram method\(^{50}\).

**Statistical Analysis of EEG Coherence Data**

The coherence is computed per electrode pair, per brain wave type, per condition for

\(^{49}\) r for real (cos-spectrum) and q for imaginary (quad-spectrum)

\(^{50}\) For a detailed explanation of the method for calculating coherence, the reader is referred to Jiang (2005).
every participant. The coherence values can then be organized into a tabular structure as seen in Table 5.5. An ANOVA test could be used to test the null hypothesis that all of the group means are equal and then applying a post hoc analysis to determine which group is significantly different for the others.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Baseline</th>
<th>…</th>
<th>Condition 1</th>
<th>…</th>
<th>Condition M</th>
</tr>
</thead>
<tbody>
<tr>
<td>E₁-E₂</td>
<td>E₁-E₃</td>
<td></td>
<td>E₁-E₂</td>
<td></td>
<td>Eₙ₋₁-Eₙ</td>
</tr>
</tbody>
</table>

Participant 1  
Participant 2  
…  
Participant N

Table 5.5: Coherence between electrodes.

**EEG indicator 3: Left-Right Symmetry**

The symmetry or asymmetry of the two brain hemispheres, left and right, while performing a task has been observed by neurophysiologist since the onset of EEG studies. Existence of symmetry between the signals recorded from the two sides, while performing a task, reflects that the two hemispheres need to work together to accomplish that task (Hugdahl & Westerhausen, 2010). Absence of symmetry between left and right shows that only one side is primarily involved, while the other hemisphere has a secondary role. The most commonly used ratio to investigate left-right (L-R) differences is the (L – R)/(L + R) ratio. This allows a straightforward interpretation of asymmetry, and tends to be normally distributed (Pivik et al., 1993). When asymmetry scores are reported, follow-up analyses assessing the unique contribution of each hemisphere, and each two corresponding lobes within a hemisphere, to the asymmetry index should be presented. For example, a finding of relatively increased right frontal activity in a given population, although an important first step, should be subjected to further analyses to
ascertain whether this pattern is due to; 1) an increase of right frontal activity; 2) a decrease of left frontal activity; or 3) a combination of activity in both lobes.

**Statistical Analysis of EEG Left-Right Symmetry Data**

Left-right symmetry is computed per wave type, per condition for every participant. Since several electrodes exist within a hemisphere, the electrode’s reading in each hemisphere is averaged before calculating symmetry. The symmetry values can then be organized into tabular structures similar to Table 5.6. Next, ANOVA followed by post hoc step is executed on the data.

In the following section, previous EEG studies of rituals from other religions are reviewed. Although the Islamic creed is different from that of the most studied group of religions, i.e. the Asian religions, reviewing those studies is important to contextualize the work, and to be able to accurately interpret the results of my study.

<table>
<thead>
<tr>
<th>Baseline Delta-L/R Symmetry</th>
<th>Baseline Theta-L/R Symmetry</th>
<th>...</th>
<th>Condition 1 Delta-L/R Symmetry</th>
<th>...</th>
<th>Condition M Gamma-L/R Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5.6: Left-Right lobes symmetry.*

### 5.3.4 Previous EEG Studies of other Religious Rituals

Researchers in the area of neuro-theology\(^{51}\) have done extensive work on Eastern religions. Various forms of Buddhist, Hindu and Confucius rituals and meditative practices have been studied. Those studies have shown that the brain state of those who

---

\(^{51}\) The scientific study of the cognitive state during religious rituals and during meditation.
are praying or meditating change during the practice. Meditation and religious rituals generally pushes the brain into more relaxed state by increasing the power of lower frequencies, such as theta and alpha, in the frontal lobe, and suppressing higher frequencies, such as beta and gamma. One exception to this pattern is a study on Tibetan monks (Lutz et al., 2004), that revealed an increase in gamma waves in the prefrontal cortex. The monks were asked to generate a feeling of compassion during meditation. One possible explanation of the Lutz results is that the data has been contaminated by EMG artifacts. The work of Whitham et al. (2007) shows that EMG contamination is a major source of artifacts for data above 20Hz.

Although neuro-theology studies disagree on the shape, intensity and reason behind the change in brain behaviour, there is a commonality in their findings; religious experiences generally have a calming effect on the brain for the average practitioner. Similar findings have been reported in studies using participants who practiced meditation in secular contexts. Table 6.7 summarizes the findings of several EEG studies on religious rituals and meditation.

Based on the evidence provided in these neuro-theological studies, I decided that EEG could indeed be used to evaluate the eRug since one would anticipate a statistically significant effect that could provide evidence of prayer quality.

<table>
<thead>
<tr>
<th>Religion</th>
<th>Power Spectrum</th>
<th>Coherence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ananada Marga</strong></td>
<td>- increased alpha and theta power</td>
<td>(Ghista et al., 1976)</td>
</tr>
<tr>
<td></td>
<td>- higher theta and alpha power (Corby, Roth, Zarcone, &amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kopell, 1978)</td>
<td></td>
</tr>
<tr>
<td>**Carmelite</td>
<td>greater theta power at left frontal lobe</td>
<td></td>
</tr>
<tr>
<td>**Christian</td>
<td>and brain mid line while greater gamma power was detected at edge of right</td>
<td></td>
</tr>
<tr>
<td>Technique</td>
<td>Changes</td>
<td></td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Qigong</strong></td>
<td>- increased alpha power frontally</td>
<td></td>
</tr>
<tr>
<td><strong>Confucianism</strong></td>
<td>(Zhang, Li, &amp; He, 1988)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- increased alpha power (Lee et al., 1997; Litscher, Wenzel, Niederwieser, &amp; Schwarz, 2001)</td>
<td></td>
</tr>
<tr>
<td><strong>Santhi Kriya</strong></td>
<td>- increased prefrontal and occipital alpha power (Satyanarayana et al., 1992)</td>
<td></td>
</tr>
<tr>
<td><strong>Hinduism</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tibetan Buddhism</strong></td>
<td>- increased theta-alpha (6–12 Hz) power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Echenhofer, Coombs, &amp; Samten, 1992)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- increased gamma power (Lutz et al., 2004)</td>
<td></td>
</tr>
<tr>
<td><strong>Zen Mahayana Buddhism</strong></td>
<td>- Alpha amplitude increased, alpha frequency decreased, alpha spreading frontally, theta bursts (Kasamatsu &amp; Hirai, 1966)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- increased frontal alpha coherence (Murata et al., 2004)</td>
<td></td>
</tr>
<tr>
<td><strong>Reflection Meditation</strong></td>
<td>- increased theta power, decreased beta power (Ikemi, 1988)</td>
<td></td>
</tr>
<tr>
<td><strong>Transcendental Meditation</strong></td>
<td>- decreased alpha frequency and increased alpha amplitude, theta bursts (Wallace, 1970), (Wallace, Benson, &amp; Wilson, 1971)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- increased intrahemispheric frontal-central and interhemispheric frontal alpha (8–10 Hz) coherence (Travis &amp; Wallace, 1999)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- increased alpha and theta coherence (Gaylord, Orme-Johnson, &amp; Travis, 1989)</td>
<td></td>
</tr>
<tr>
<td><strong>Yoga</strong></td>
<td>- Alpha activity increase (Wenger &amp; Bagchi, 1961)</td>
<td></td>
</tr>
<tr>
<td><strong>Raj</strong></td>
<td>- increased alpha power (Anand, Chhina, &amp; Singh, 1961)</td>
<td></td>
</tr>
<tr>
<td><strong>Kundalini Yoga</strong></td>
<td>- increased alpha power (Arambula, Peper, Kawakami, &amp; Gibney, 2001)</td>
<td></td>
</tr>
<tr>
<td><strong>Sahaja Yoga</strong></td>
<td>- increased theta and alpha power in frontal-central (Aftanas &amp; Golocheikine 2001, 2002)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- increased theta coherence (Aftanas &amp; Golocheikine, 2003)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.7: Summary of EEG studies on religious ritual and meditation – adapted from (Cahn & Polich, 2006).
Studies focusing on religious rituals are unique when it comes to participants’ selection. While the norm is to select participants randomly from the general population, and test for normality in the analysis, studies on religious rituals exclude all but the experts in the ritual being studied. The following section is dedicated to the issue of selecting participants for the planned studies; the rationale behind the approach is discussed.

5.4 Participant Selection and the Religiosity Questionnaire

Two fundamental design assumptions that do not hold in conducting experiments involving religious rituals are; all participants, regardless of their proficiency, will have statistically similar baseline performance, and all participants are affected in a linear manner by the stimulus. Previous studies of religious ritual have shown that a ritual could have a profound impact on an expert while much less impact is witnessed on a novice. Furthermore, experts seem to maintain a cognitive state characterized by relaxation and contemplation, throughout their day, while average and novice users are more susceptible to stress and consequently mental exhaustion, and more variable mental states. Lutz et al. (2003) found, for example, that adherents respond differently to interruptions depending on the level of religious practice they have achieved. In an experiment designed to measure the effect of distracters on praying, practitioners were instructed to concentrate on a stimulus, and when their attention wandered off, to simply bring it back to the object. The subjects meditated inside an MRI scanner, while the researchers periodically introduced disturbing noises. Among the experienced meditators, the noise was found to have less effect on the brain areas involved in emotion and decision-making than among the more novice meditators. In the case of meditators with more than 40,000 hours of
lifetime practice, these brain areas were hardly affected at all by the disturbances. Using a randomly selected pool of participants which includes a mix of novice, average and expert participants could conceal some of the subtleties in the recorded data. An increase of 10%, in an independent variable, scored\textsuperscript{52} by an average practitioner does not necessarily have the same weight than an increase of 10% scored by an expert. In addition, the average practitioner’s 10% typically translates to a few points of increase on a linear scale, while the 10% recorded by an expert could translate to a multiple of those points. In secular activities, this type of problem forces the researcher to use a statistical technique that would take the categorical difference between participants into consideration (e.g., employ an analysis of covariance).

Neuro-theology researchers tend to focus on expert participants since the investigated effect – if it exists – will be profound and will be uncovered even with a low participant count. As a result most neuro-theology experiments are conducted with fewer than 10 expert participants and in some cases with as low as 4 participants\textsuperscript{53}.

In the case of Islam, the need to identify novice, average and expert practitioners poses a problem for the researcher. The religious duties of a Muslim scholar are not different from any other Muslim. Priesthood, as it is commonly understood in Christianity, Hinduism, or Buddhism, is not part of Islam. Muslim scholars are not required to devote major portions of time to worship. A Muslim scholar is a term used to describe someone who is devoted to the scholarly study and investigation of a specific aspect of the religion. Furthermore, Muslims are instructed, by the religion, to conceal the performance of all but mandatory group-rituals. This instruction aims to protect the practitioner from

\textsuperscript{52} The semantics of units on a scale measuring performance during a religious ritual is still an unchartered territory in neuro-theology.

\textsuperscript{53} For example, most of the studies cited in section 5.3.4 were done with eight or less participants.
being identified as more pious which in turn might invoke internal feelings of superiority and arrogance in the praised individual – feelings that are admonished in Islam. Since the eRug was intended for average practitioners, the identification of this group of Muslims was paramount for an evaluation to be conducted.

The Muslim Religiosity Personality Measurement Inventory (MRPI) was used to measure religiosity of volunteers for the eRug experiments (Krauss et al., 2005) The MRPI was developed to measure the religiosity and practice of rituals among Muslim youth. The MRPI questions are included in Appendix F. Evaluated on a very large sample size\(^{54}\) by Krauss et al. (2005), the questionnaire showed high internal reliability; for the Islamic Worldview scale, the alpha was .82 while for the Religious Personality scale, the alpha was .91.

The MRPI consists of two parts; measuring the adoption of the person to the Islamic worldview and Religious Personality. The adoption measure is the set of beliefs that constitutes the Islamic dogma and the religious personality (Figure 5.8). For the Islamic Worldview scale, a five-point scale was used ranging from (1) "Not at all in agreement with my view" to (5) "Exactly the same as my view," in line with the objective of the scale which was to determine respondents understanding of Islamic creed and foundational beliefs. For the, Religious Personality measure, a five-point scale was also used ranging from (1) "I rarely do this" to (5) "I always do this," to measure a range of behaviours that represent the manifestation and spirit of Islamic worldview in everyday life, including but not limited to ritual behaviors and actions toward others, oneself, and the natural world at large.

\(^{54}\) N=1,692 participants.
Since the eRug was developed with the aim of enhancing the performance of average Muslims, the MRPI was used to select users belonging to this category in the Muslim population. The volunteers for the eRug studies had to complete the MRPI questionnaire prior to the study. Only those who scored between 50 and 68 (considered an average user) in the MRPI were recruited.

Although the participants interviewed early on\textsuperscript{55} were seniors ($M$ (age) = 64.6 yrs, $SD = 3.9$), the participants for the three eRug studies were much younger; ($M$ (age) = 25.5 yrs, $SD = 2.25$), ($M$ (age) = 34.9 yrs, $SD = 5.5$), and ($M$ (age) = 30.3 yrs, $SD = 4.1$) \textsuperscript{56} respectively. The reason behind selecting a younger sample is that an individual’s brain changes with age and the EEG recording reflect those changes (Crespel & Gélisse, 2005).

To avoid introducing age as a new factor in the study, participants between the ages of 20 and 50 were selected.

\textsuperscript{55} Reported in Chapter 2.

\textsuperscript{56} Reported mean age and standard deviation is for all participants in a study. Detailed profile of participants is reported in each experiment’s section separately.
5.5 Experiment 1: EEG of Muslims during Salah

Due to the lack of EEG studies on Muslims during prayer, an initial study had to be conducted to investigate if Salah has a recognizable effect. To limit the number of conditions and variability in the experiment, only Salah without the eRug was considered.

5.5.1 Research Questions

The aim of this experiment was to study the brain of Muslims, using EEG, while praying and answers basic questions related to the practice; what changes, if any, happen in the different brain areas of a Muslim while performing Salah? Can these changes confirm the reported feelings? And do these changes resemble those reported for other religions?

5.5.2 Hypothesis

\( H_1: \) EEG power spectrum will not change during Salah as compared to Baseline.

\( H_2: \) EEG coherence will not change during Salah as compared to Baseline.

5.5.3 Experimental Design

The experiment had three conditions, all accompanied by EEG recording: a *Baseline* during which the participant would sit in a chair without moving, a *Salah* condition during which the participant performs a prayer, and a *Control* during which the participant performs the physical actions performed during Salah but without actually being in prayer. The *Control* was added to be able to identify and separate the spiritual impact of the ritual from the impact of the physical movements. As previously discussed
in section 5.2, Burns (2001) stipulated that the feelings experienced during Salah are due to the yoga-like movements. Considering that the eventual goal was to evaluate the impact of the eRug, then if the Salah’s effect was only due to the physical movements, then the eRug would not enhance the participants’ performance since it does not add to, or modify, the postures and further evaluation would be unwarranted.

5.5.4 Participants

Thirteen males ($M$ (age) = 25.5 yrs, $SD$ = 2.25) with no history of psychiatric, neurological or substance use disorders\(^{57}\) participated in this study. They were not taking any psychotropic drug at the time of the study. All participants were right handed\(^{58}\) Sunni Muslims, who had practiced Salah on a daily basis since childhood. They were all professionals from scientific disciplines – nine had post-graduate degrees. All participants spoke Arabic, the original language of the Quran, as their mother tongue. All participants studied basic Islamic knowledge in the elementary and secondary schools. Hence, they possessed a general understanding of important Islamic dogma. On average, participants reported having memorized 15 pages ($SD$ = 5.3) from the Quran. The 13 participants average score on the MRPI was 60.8 ($SD$ = 4.7) and met the inclusion criterion of an MRPI score of 50-68. Table 5.8 lists the profile of each participant.

\(^{57}\) According to self-reports.
\(^{58}\) EEG of left handed individuals is slightly different from those that are right handed. To avoid introducing a new factor in the experiment, all participants were asked and they confirmed being right handed.
5.5.5 Procedure

When participants arrived in the laboratory they read an information sheet, signed a consent form (Appendix H) and completed a demographic questionnaire (Appendix I). Ethics approval was provided by the University of Toronto ethic board. Before the onset of the experiment, participants made ablution as it is condition for performing Salah. They were instructed that it was important to “disconnect from the material world and try to perform the Salah in concentration”. The participants were also told to “spend time in each ritual posture” as this helps in stabilizing the EEG signal. Next, two EEG electrode collector-boxes were mounted on the upper back of the participant and fixed in place using an adhesive tape. A Speedo™ non-conductive swimming cap embedded with EEG electrodes was placed on the participant's head (Figure 5.9). For each electrode, a small amount of Ten20™ conductive paste was inserted through an opening. The paste improved the electrical connection and provided a temporary bond to hold the electrode

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Quran Pages Memorized</th>
<th>MPRI Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>10</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>12</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>24</td>
<td>67</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>14</td>
<td>59</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>16</td>
<td>63</td>
</tr>
<tr>
<td>6</td>
<td>23</td>
<td>14</td>
<td>58</td>
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<tr>
<td>7</td>
<td>25</td>
<td>10</td>
<td>57</td>
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<td>8</td>
<td>23</td>
<td>19</td>
<td>65</td>
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<tr>
<td>9</td>
<td>25</td>
<td>11</td>
<td>56</td>
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<tr>
<td>10</td>
<td>23</td>
<td>12</td>
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<td>11</td>
<td>23</td>
<td>10</td>
<td>63</td>
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<tr>
<td>12</td>
<td>24</td>
<td>26</td>
<td>67</td>
</tr>
<tr>
<td>13</td>
<td>26</td>
<td>19</td>
<td>67</td>
</tr>
</tbody>
</table>

Table 5.8: Experiment 1 participants’ profile

---

59 Cleansing procedure which involves washing the hands, arms, face, and feet.
on the scalp. The experiment always began with the *Baseline* condition measurement during which the participant would sit comfortably in a chair for 5 minutes, and were asked to relax but stay alert and open eyed\(^{60}\). The allocation of the order in which the two conditions, *Salah* or *Control*, were performed was randomly assigned, and subsequently counterbalanced, such that six participants began with the *Salah* condition and seven participants began with the *Control* condition. Participants *Salah* condition and seven participants began with the *Control* condition. Participants performed the experiment in an air-conditioned, sound attenuated recording room. Each experimental session required approximately 40 minutes to complete. During the *Salah* condition, the participants were left unattended.

*EEG Recording*

EEG signals were recorded from 25 sintered electrodes approximately located near the following montage positions: FPz, Fz, F3, F4, F7, F8, AF7, AF8, C1, C2, C3, C4, CP1, CP2, CPz, P3, P4, P7, P8, Pz, T3, T4, PO3, PO4, and Oz – as shown in Figure 5.10. All channels were referenced to Nz, grounded through Iz, and amplified using a bank of Grass amplifiers with a 20,000x amplification factor. All electrode impedances were maintained at less than 5 kΩ. The amplified signals were recorded using a Windows XP

\(^{60}\) Closing the eyes changes the recorded EEG.
computer and a National Instruments PCI-MIO-16XE-50 data acquisition board with a 16-bit analog to digital resolution. The data were recorded using a custom script, running in Labview (2007). The EEG was band pass filtered (1 to 100Hz) at the source and digitized at 256 samples per second (256 Hz). Data analyses were carried out using Matlab (2010) and EEGLAB (Delorme & Makeig, 2004), an open source toolbox for EEG. First, the EEG data were visually scored for artifact due to motor movements using EEGLab. This program removed data from all channels if an artifact was present on any one channel.

Artifacts due to intra-posture movements were easily detectable due to extreme noise associated with physical movement. Five poor channels were identified and replaced using spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989). The major artifact of EEG is eye movement artifact is laid in delta and theta bands (Hagemman & Naumann, 2001). Artifacts were corrected using the Automatic Artifact Removal (AAR) Toolbox version 1.3 (Gómez-Herrero et al., 2006), an EEGLab plugin. After examining the results of all of the AAR filters available, a blind source separation
using canonical analysis (BSSCA) was selected as the optimum filter for removing the artifacts. BSSCA is based on statistical canonical correlation analysis (Hotelling, 1936) applied as a blind source separation (BSS) technique. To solve the BSS problem, BSSCA assumes mutually uncorrelated sources which are maximally autocorrelated (Friman, Borga, Lundberg, & Knutsson, 2002). BSSCA was successful in the separation of muscle and brain activity sources because of the relative low autocorrelation of muscle artifacts in comparison with brain activity. To further eliminate noise from muscle sources, the first and last five seconds from each recording was rejected. The participants performed Salah without errors and hence the recorded EEG data did not require further adjustments.

5.5.6 Data Analysis

All EEG variables were checked for distribution normality by using the Shapiro-Wilk test and were normalized by a logarithmic transform (Shapiro & Wilk, 1965). EEG data from each condition were first summed to 5 bands (delta, theta, alpha, beta, and gamma) and each band was compared to its counterpart in the different conditions using repeated measures ANOVA with condition as the within-subjects factor. Next, the same type of analysis was repeated to investigate inter-lobe differences. Using SPSS (2010), Mauchly's test (Mauchly, 1940) was used to determine whether the assumption of sphericity was been violated. If Mauchly’s test was significant and the output epsilon is > 0.75, the Huynh-Feldt correction was applied to the degrees of freedom, otherwise the Greenhouse-Geisser correction was used (Field, 1998)\textsuperscript{61}. Whenever significance was

\textsuperscript{61} To avoid repetition, Mauchly’s statistic (W) and epsilon (ε) are reported after p value where appropriate.
found, Bonferroni-corrected post-hoc tests were used to uncover the significant pairs. Statistical significance was defined as $p<.05$.

### 5.5.7 Results

*Power Analysis*

Statistical analysis was first performed on the overall EEG Log$_e$ data for each of the five bands. Delta ($F_{1.62, 478.23}=367.39$, $p <.05$, $W(2) = .69$, $\varepsilon = .71$), theta ($F_{1.58, 495.03}=467.23$, $p <.05$, $W(2) = .79$, $\varepsilon = .81$), and alpha ($F_{1.54, 482.26}=374.95$, $p<.05$, $W(2) = .77$, $\varepsilon = .82$) witnessed a significant change. Beta and gamma did not show a significant change. Post-hoc tests showed that there was a significant difference in EEG power between *Salah* and *Baseline* conditions in the three bands. There was no interaction between any two conditions and a third. Hence, the null hypothesis $H_1$ has been invalidated. There was no significant difference in EEG power between *Baseline* and *Control*. Table 5.9 shows the overall mean and standard deviation for each of the five bands. During *Salah*, mean delta increased by 37%, mean theta increased by 50%, and mean alpha increased by 31%. Power ratios were calculated for the five bands and showed an increase in delta, theta and alpha ratios accompanied by a drop in beta and gamma ratios. Next, using Log$_e$ Power, EEG data was averaged in for the six main brain regions: frontal lobe (AF8,F4,F8,AF7,F3,F7,FPz,Fz), central sulcus (C1,C2,C3,C4), temporal lobe (T3,T4), parieto central (CPz,CP1,CP2), parietal lobe (P3,P7,P4,P8,Pz), and occipital lobe (Oz,PO3,PO4).
Table 5.9: Experiment 1 overall spectral power and power ratios. Mean ± standard deviation. * Spectral power in Salah is significantly different from Baseline, p<.05.

Table 5.10 shows the mean and standard deviation of different lobes. A repeated measures ANOVA was used to examine differences in power levels for each region between the different conditions. The frontal and parietal lobe exhibited the same pattern of change as the overall power; an increase in delta, theta and alpha waves and a decrease in beta and gamma. In the frontal lobe; during Salah delta increased by 113% \( (F_{2,24}=140.52, p<.05) \), theta increased by 54% \( (F_{2,24}=108.23, p<.05) \), alpha increased by 15% \( (F_{2,24}=99.75, p<.05) \), while beta dropped by 10% \( (F_{1.56,18.36}=84.32, p <.05, W(2) = .43, \varepsilon = .59) \). Similarly, gamma decreased by 25% \( (F_{2,24}=108.52, p<.05) \).
During Salah, the parietal lobe witnessed the following changes: delta increased by 67% (F_{2,24}=213.76, p<.05), theta increased by 43% (F_{2,24}=103.11, p<.05), and alpha increased by 9% (F_{2,24}=57.29, p<.05). Beta dropped by 6% (F_{1.52,16.78}=47.38, p<.05, W(2) = .31, ε = .67). Gamma also decreased by 22% (F_{2,24}=69.74, p<.05). The only other significant change was in the temporal lobe where alpha increased by 5% (F_{2,24}=136.56, p<.05).

Pair wise comparison between left and right sides in each lobe were conducted for the five bands. No significance was found indicating a possible absence of a lateral shift to either side or that more participants were required.

**Coherence Analysis**

EEG coherence was computed for all 300 intra-hemispheric\(^{62}\) and inter-hemispheric\(^{63}\) pair wise combinations of the 25 channels in each of the 5 frequency bands. A repeated-measures ANOVA was used to analyze EEG coherence. Post hoc t-tests were carried out

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\(^{62}\) Across the two brain lobes – left and right.

\(^{63}\) Within the same brain lobe.
where appropriate. Out of the 1500 pairs (300 combinations x 5 spectra), 23 pairs (Figure 5.11) were found to show statistically significant coherence changes (p < .05) between *Salah* and *Baseline* in the three bands: delta, theta and alpha. Hence, the null hypothesis H₂ has been invalidated. The significant pairs were distributed between the frontal (7 pairs), central sulcus (6 pairs), parietal (2 pairs) and temporal lobes (8 pairs).

Table 5.11 shows the average change per lobe in each of the three bands. Mean coherence for the three bands increased in frontal, central and temporal lobes, while the parietal lobe pairs witnessed a drop in alpha coherence. Table 5.12 shows the individual coherence values for each pair in *Baseline* and in *Salah*. All pairs in each of the frontal, central and temporal showed an increase in coherence while the two parietal-frontal pairs witnessed a drop.

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**Figure 5.11: Experiment 1 coherence.** Dotted line shows pairs whose coherence increased significantly in *Salah* compared to *Baseline*. (a) Delta waves pairs. (b) Theta waves pairs. (c) Alpha waves pairs.

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64 A value '0' means that the two signals are completely uncorrelated, while a value '1' means that the 2 signals are completely correlated.
<table>
<thead>
<tr>
<th>Lobe</th>
<th>Pairs</th>
<th>Delta</th>
<th>Theta</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal</td>
<td>AF7-AF8, AF7-F8, AF8-F7, F3-F4, F7-F8, F3-Fz, F4-Fz</td>
<td>+46%</td>
<td>+61%</td>
<td>+61%</td>
</tr>
<tr>
<td></td>
<td>C2-F4, C2-T4, C4-AF8, C4-F4, C4-P4, C4-T4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>P3-F7, P4-F8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parietal</td>
<td>T3-F3, T3-F7, T3-Fz, T3-P3, T4-F3, T4-Fz</td>
<td>+38%</td>
<td>+50%</td>
<td>+76%</td>
</tr>
</tbody>
</table>

Table 5.11: Experiment 1 percentage coherence change per region.
Table 5.12: Experiment 1 electrode pairs with statistically significant change. Values shown are for coherence mean values ± standard deviation. Grayed areas did not show significance between Baseline and Salah. Coherence decrease is labeled with a down arrow (↓). p<.05.

5.5.8 Discussion

Power Analysis

It may be possible to physiologically interpret the reported feelings of Muslims during Salah as a consequence of the changes in the frontal and parietal lobes. The increase in delta, theta and alpha bands have been shown to have a direct effect on the release of immune boosting hormones such as DHEA, and suppression of epinephrine and cortisol – the later related to stress and anxiety (Johansson & Uneståhl, 2006). These in turn cause a relaxing condition in the human body through activation of the parasympathetic nervous system. Hence, the practice of Salah may indirectly affect a practitioner’s health by decreasing stress. This further supports the claim by researchers that there is a correlation between Salah and recovery from alignments and also between Salah and

\[ \begin{align*}
T3-F3 & \quad 0.677 \pm 0.11 & 0.897 \pm 0.09 & 0.582 \pm 0.12 & 0.797 \pm 0.09 & 0.482 \pm 0.15 & 0.799 \pm 0.16 \\
F_{2,24} = 11.6 & & F_{2,24} = 8.3 \quad F_{2,24} = 7.1 \\
T3-F7 & \quad 0.681 \pm 0.09 & 0.885 \pm 0.11 & 0.631 \pm 0.09 & 0.842 \pm 0.12 & 0.601 \pm 0.09 & 0.810 \pm 0.11 \\
F_{2,24} = 12.2 & F_{2,24} = 13.0 \quad F_{2,24} = 10.7 \\
T3-Fz & \quad 0.562 \pm 0.08 & 0.764 \pm 0.12 & 0.517 \pm 0.12 & 0.769 \pm 0.13 & 0.351 \pm 0.09 & 0.598 \pm 0.13 \\
F_{2,24} = 9.1 & F_{2,24} = 8.3 \quad F_{2,24} = 7.0 \\
T3-P4 & \quad 0.549 \pm 0.11 & 0.783 \pm 0.12 & 0.527 \pm 0.08 & 0.708 \pm 0.09 & 0.324 \pm 0.12 & 0.592 \pm 0.14 \\
F_{2,24} = 8.9 & F_{2,24} = 7.5 \quad F_{2,24} = 7.7 \\
T3-Pz & \quad 0.581 \pm 0.09 & 0.769 \pm 0.09 & 0.509 \pm 0.12 & 0.764 \pm 0.13 & 0.414 \pm 0.13 & 0.699 \pm 0.15 \\
F_{2,24} = 12.3 & F_{2,24} = 10.0 \quad F_{2,24} = 7.3 \\
T3-T4 & \quad 0.385 \pm 0.09 & 0.594 \pm 0.11 & 0.320 \pm 0.14 & 0.589 \pm 0.12 & 0.264 \pm 0.14 & 0.598 \pm 0.17 \\
F_{2,24} = 17.3 & F_{2,24} = 7.7 \quad F_{2,24} = 11.3 \\
T4-F3 & \quad 0.356 \pm 0.11 & 0.588 \pm 0.12 & 0.261 \pm 0.15 & 0.593 \pm 0.18 & 0.233 \pm 0.10 & 0.498 \pm 0.16 \\
F_{2,24} = 15.6 & F_{2,24} = 8.4 \quad F_{2,24} = 8.0 \\
T4-Fz & \quad 0.603 \pm 0.08 & 0.789 \pm 0.10 & 0.477 \pm 0.09 & 0.691 \pm 0.12 & 0.301 \pm 0.15 & 0.642 \pm 0.18 \\
F_{2,24} = 12.0 & F_{2,24} = 10.9 \quad F_{2,24} = 9.9
\end{align*} \]
overall good health\textsuperscript{65}.

The same pattern of change in the parietal lobe decreases awareness of the surrounding stress-inducing environment, as thoughts are largely inhibited or suspended. The only other statistically significant change was recorded near the auditory region, where an increase was recorded in the alpha band. During Salah, the participants moved their lips while reciting Quran verses. The alpha waves near the auditory region may indicate that the participants were listening to their own whispered recitation as they performed the Salah, or imagined hearing the words.

Salah shares with eastern meditation the increase in delta, theta and alpha (e.g. Banquet 1973). A major difference between Salah and other religious rituals was that the participants involved in this study were drawn from the general Muslim population while participants in related studies of other religions relied exclusively on expert practitioners. The regularity and frequency of Salah, combined with the underling Islamic dogma, could be the reasons behind the significant impact of the ritual even on average practitioners.

An adult Muslim is required to pray from puberty. Praying five times a day, every day, presents an excellent opportunity for the practitioner to train her mind on disconnecting from the physical world and reaffirming the Islamic dogma that a Muslim is a servant of God and must surrender to Him in all aspects. This notion of surrendering to God is central in Islam\textsuperscript{66}. The goal of Salah then is to surrender to God (Mababaya, 2006). This is achieved by letting all worldly thoughts go away and being assured that one is between

\textsuperscript{65} Sections 1.1 and 5.2 provide an overview of relevant studies.

\textsuperscript{66} The word Arabic Islam itself means submission or surrender.
the hands of God\textsuperscript{67} (Mababaya, 2006). Any active thinking of worldly affairs is considered inappropriate and violates the goal of Salah. When active thinking is reduced, beta and gamma power is supposed to decrease and allowing slower frequencies to occur. The more Salah is practiced, the more the practitioner may be able to switch his or her brain waves to slower frequencies. Although the study participants were not experts, in the sense of dedicating their life to being men of religion, their performance seemed to show that Salah enabled them to produce performance comparable to experts of other religions. During Salah, the participants performed four interleaved mental tasks: executing physical movements, reciting the Quran, making supplication and disconnecting from the surrounding physical world. The analysis revealed that performing the physical steps without being in Salah (\textit{Control} condition) did not have an effect. There was also no significant difference in EEG power between \textit{Baseline} and \textit{Control} which indicates that just mimicking the movements may not produce a cognitive effect or that there were too few participants to show an effect. This indicates that either one of the other three mental tasks or an interaction between them may be creating the identified effect. Performing the free-form supplication in the sajdah\textsuperscript{68} posture might cause a strong emotional reaction and consequently affect the EEG. Analyzing EEG per posture requires a method of tracking the execution of different steps in Salah, for example by using a video camera. However, to avoid affecting the participant concentration, such intrusive monitoring mechanisms were avoided in this initial study due to its exploratory nature and therefore I am unable to perform a per posture analysis of the data. Hence, it is unclear from the current study which of the four tasks, or a combination of them, caused the observed

\textsuperscript{67} The mandatory chapter one, Salah supplications and the physical movements are all manifestations of this belief.

\textsuperscript{68} Illustrated in Figures 2.1e and 2.1f.
Coherence analysis revealed a complex web of pairs interacting with each other to enable the performance of Salah. Twenty-three pairs exhibited significant change in the three bands: delta, theta and alpha bands. Two pairs connecting the parietal lobe to the frontal lobe, P3-F7 and P4-F8, showed a significant drop in coherence during Salah, as compared to Baseline and Control. The parietal lobe is involved in detecting orientation and generating a sense of awareness of space (Kusonoki & Goldberg, 2003; Goldberg, Bisley, Powell, & Gottlieb, 2006; Avillac et al., 2005; Zhang, Heuer, & Britten, 2004), while the frontal lobe is considered the center of biological intelligence and consciousness (Beaumont, 2008; Orrison, 2009). A drop in coherence between these two lobes may indicate a decrease in the awareness information communicated between them, and could be the reason behind the reported spiritual and uplifting feeling.

Salah’s physical steps and postures can be considered as goal-directed movements which the various brain areas must cooperate to perform. Previous research has shown that to carry out goal-directed movements, the motor cortex must first receive information from several lobes: first; information about the goal to be attained and an appropriate strategy for attaining it from the anterior portion of the frontal lobe, second; information about memories of past strategies, from the temporal lobe, and third, information about the body's position in space, from the parietal lobe (Beaumont, 2008). Several pairs that showed significant increase during Salah and Control conditions in this study could be related to performing the ritual physical steps and gestures: C4-F4, C4-AF8, and C2-F4 to communicate goal information, C2-T4 and C4-T4 to communicate memories about the
execution strategy while C4-P4 to communicate orientation information.

Salah involves recalling Quran verses from memory. Eight temporal lobe pairs showed significant increase during *Salah* condition as compared to *Baseline* and *Control* conditions. The pairs were temporal to frontal; T3-F3, T3-F7, T3-Fz, T4-F3, and T4-Fz, temporal to parietal; T3-P4 and T3-Pz, and temporal to temporal; T3-T4. Most of the pairs were on the left side of the brain indicating that they may be related to ‘internal’ recitation of the Quran verses. The pairs were recorded in delta, theta and alpha bands. Previous research has shown that the lower EEG frequency coherences were correlated with memory processes (Beaumont & Rugg, 1979; Klimesch et al., 1990; Sarnthein et al., 1998; Weiss & Rappelsberger, 2000). Delta and theta coherences, between and within the frontal and temporal lobes, are related to the successful encoding and decoding of information (Weiss & Rappelsberger, 2000; Summerfield & Mangels, 2005) while alpha coherence is related to processing the semantics of the information (Mima, Oluwatimilehin, Hiroak, & Hallet, 2001). This further indicates that the eight identified pairs are likely related to recalling Quran verses.

During *Salah*, the participants attempt to concentrate and attenuate during the ritual. Nine pairs AF7-AF8, AF7-F8, AF8-C4, AF8-F7, F3-F4, F3-Fz, F4-Fz, F4-P4, and F7-F8, all in frontal lobe showed significant coherence increase, which is indicative of concentration and attenuation (Beaumont, 2008). Previous research has shown that most human activities are either left lateralized or right lateralized in the frontal lobe. For example, language functions such as grammar and vocabulary often are lateralized to the left hemisphere of the brain (Taylor & Taylor, 1990). In contrast, prosodic language functions, such as intonation and accentuation, often are lateralized to the right
hemisphere of the brain (Taylor & Taylor, 1990). During Salah, most frontal pairs are left-right pairs. The two sides show a remarkably balanced inter-communication as though interplay between functions on both sides is needed for performing the ritual.

5.5.9 Limitations

There are a number of limitations to this study that suggest that the results must be cautiously interpreted. The first limitation is the effect of ablution on the participant. Muslims often report that performing ablution prior to Salah helps them in clearing their mind in preparation for Salah. The procedure of cleaning the head, arms, hands and feet resembles a quick massage. Several works have showed that massage affects EEG recording results (e.g. Jodo, 1988). However, those studies administered more focused massage and for longer periods of time. In this study, participants performed the ablution before the baseline, and hence any possible effect was recorded as part of both; the Baseline and the Salah conditions. Such effect should be consistent across both conditions. Further studies are required to investigate whether ablution has any effect in EEG results.

This study also suffers from gender and age bias. Only male participants were used due to the difficulty in locating female Muslim volunteers in Toronto. Participants were mostly graduate Muslim students and hence the age range of the subjects is small.

Another issue that should be addressed in future studies is to use participants whose mother tongue is not Arabic. In this study, all participants had Arabic as their mother tongue and hence they likely had a better understanding of the Quran’s literal and metaphoric meaning than non-Arabic speaking Muslims who often recite the Quran
without fully grasping the meaning. Arabic speaking participants were recruited for this study to eliminate the possible language effect that might interact with the other variables in the experiment. The limited number of participants in the experiment is another limitation. Due to the relatively small Arab Muslim population in Toronto, it was difficult to recruit a larger number of participants.

Three possible other limitations; 1) the lack of posture data, 2) the location of the study – being a university lab, a place which neither resemble a mosque nor where familiar to participants, and 3) the EEG apparatus being too intrusive. However, if there was an effect due to either of these, it was factored into all the three conditions.

5.6 Experiment 2: EEG of Muslims during Salah on eRug

After confirming that Salah seems to change the cognitive state of the user, a follow up experiment was launched to evaluate the impact of using the eRug in the ritual.

5.6.1 Research Questions

Although the eRug form is similar to the traditional rug, several additions were made, namely; a screen, touch sensors, sonar sensor, and vibration disc motor. In addition, the material was changed from being cotton/silk to being plastic-based. Evaluating the eRug then also entails determining whether the user will be distracted by these additions. Will the user performance change because they know that errors will be detected? What changes, if any, will the brain signature of the user undergo during prayer on eRug? Whatever change Salah induced must at least be maintained, if not improved, by the eRug to be able to claim that the eRug does not affect the quality of prayer negatively.
5.6.2 Hypothesis

$H_3$: EEG power spectrum will be similar in Salah on the eRug compared to Salah without eRug.

$H_4$: EEG coherence will be similar in Salah on the eRug compared to Salah without eRug.

5.6.3 Experimental Design

The experiment had three conditions, all accompanied by EEG recording: *Baseline* – during which the participant would sit in a chair without moving, *Control* – the participant would perform a prayer on a traditional rug during which the Quran used verses are recalled from memory, and *eRug* – the participant would perform a prayer on the eRug during which the participant would be reading new Quran verses from the eRug screen.

Since the experiment involved reading Quran verses from the eRug screen and participants could have memorized any subset of those verses, participants were contacted prior to the commencement of the study to find which verses each memorizes. A set of verses, which none of the participants had memorized, were selected for the *eRug* condition, so that all participants are reading un-memorized verses.

5.6.4 Participants

An advertisement was placed in local mosques in Toronto soliciting participants in the study (see Appendix G). An MRPI score outside the range 50-68 was used as an
exclusion criterion. Out of an initial 29 volunteers, 16 volunteers qualified for the experiment (\(M\) (age) = 34.9 yrs, \(SD = 5.5\)). Table 5.13 lists the participants’ profile. The 16 participants average score on the MRPI was 59.4 (\(SD = 5.2\)). The participants neither reported a history of psychiatric, neurological or substance use, nor were taking any psychotropic drug at the time of the study. All participants were right-handed\(^{69}\) Sunni Muslims, who practiced Salah on a daily basis since childhood. They were all professionals – nine studied scientific or engineering disciplines, and seven studied arts or business. All participants studied basic Islamic knowledge for 12 years in school, and had Arabic as their mother tongue. They could be considered as possessing a general understanding of important Islamic dogma.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Quran Pages Memorized</th>
<th>MRPI Score</th>
</tr>
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<tbody>
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<td>32</td>
<td>16</td>
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<td>52</td>
</tr>
</tbody>
</table>

Table 5.13: Experiment 2 participants’ profile

\(^{69}\) EEG of left handed individuals is slightly different from those that are right handed. To avoid introducing a new factor in the experiment, all participants were asked and they confirmed being right handed.
5.6.5 Procedure

When participants arrived in the laboratory they read an information sheet, signed the consent form (Appendix H) and completed a demographic questionnaire (Appendix I). Before the onset of the experiment, participants made ablution\(^{70}\) as it is condition for performing Salah. They were instructed that it was important to “disconnect from the material world and try to perform the Salah in concentration”. The participants were also told to “spend time in each ritual posture” as this helped in stabilizing the EEG signal. Next, two EEG electrode collector-boxes were mounted on the upper back of the participant and fixed in place using an adhesive tape. A Speedo™ non-conductive swimming cap embedded with EEG electrodes was placed on the participant's head. For each electrode, a small amount of Ten20™ conductive paste was inserted through an opening. The paste improved the electrical connection and provided a temporary bond to hold the electrode on the scalp. The experiment always began with the Baseline condition during which the participant would sit comfortably in a chair for 5 minutes, and were asked to relax but stay alert and open eyed\(^{71}\). The allocation of the order in which the two experimental conditions, eRug or Control, were performed was randomly assigned, and subsequently counterbalanced, such that an equal number of participants began with the eRug condition as those that began with the Control condition. Participants performed the experiment in an air-conditioned, sound attenuated recording room. Each experimental session required approximately 60 minutes to complete. During the eRug and Control conditions, the participants were left unattended. The participants performed both prayer conditions without errors.

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\(^{70}\) Cleansing procedure which involves washing the hands, arms, face, and feet.

\(^{71}\) Closing the eyes changes the recorded EEG.
5.6.6 Data Analysis

During the experiment, three participants withdrew because they suspected that praying on the eRug was not religiously permissible. The data for those participants were discarded. Next, all EEG variables were checked for distribution normality by using the Shapiro-Wilk test and were normalized using a logarithmic transform (Shapiro & Wilk, 1965). EEG data from each condition were first summed to the five bands and each band was compared to its counterpart in the different conditions using repeated measures ANOVA with condition as the within-subjects factor. Next, the same type of analysis was repeated to investigate inter-lobe differences. Repeated-measures designs have the assumption of sphericity which means that the variance of the population difference scores for any two conditions should be the same as the variance of the population difference scores for any other two conditions. Using SPSS (2010) Mauchly's test (Mauchly, 1940) was used to determine whether the assumption of sphericity was been violated. If Mauchly’s test is significant and the output epsilon is > .75, the Huynh-Feldt correction was applied to the degrees of freedom, otherwise the Greenhouse-Geisser correction was used (Field, 1998). Whenever significance was found, Bonferroni-corrected post-hoc tests were used to uncover the significant pairs. Statistical significance was defined as p<.05.

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72 At that point in time, the scholar did not yet provide a formal religious opinion that praying on the eRug is permissible.
73 To avoid repetition, Mauchly’s statistic (W) and epsilon (ε) are reported after the p value where appropriate.
5.6.7 Results

*Power Analysis*

Statistical analysis was first performed on the overall EEG Log_e data for each of the five bands. There was a statistically significant main effect for three bands, delta, theta and alpha, between the three conditions. Table 5.14 shows the overall mean and standard deviation for each of the five bands.

Comparing the *eRug* to the *Baseline*; delta increased by 46% (F_{1,4,418.2}=452.8, p<.05, W(2)=.8, ε=.79), theta increased by 83% (F_{1,32,418.7}=493.2, p<.05, W(2)=.72, ε=.82), and alpha increased by 57% (F_{1,52,401.4}=475.9, p<.05, W(2)=.69, ε=.76) while praying on the eRug. The *Control* also produced a statistically significant impact as compared to the *Baseline*; theta increased by 49% (F_{1,43,319.1}=389.3, p<.05, W(2)=.61, ε=.72), and alpha increased by 34% (F_{1,54,402.5}=402.8, p<.05, W(2)=.8, ε=.79). Comparing the *eRug* to the

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Control</th>
<th>eRug</th>
<th>% Control Change</th>
<th>% eRug Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Log power (ln µV^2)</strong></td>
<td></td>
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<tr>
<td>Delta</td>
<td>0.73 ± 0.15</td>
<td>1.01 ± 0.18</td>
<td>1.11 ± 0.16*</td>
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<td>+46.00</td>
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<tr>
<td>Theta</td>
<td>1.59 ± 0.14</td>
<td>1.99 ± 0.16*</td>
<td>2.19 ± 0.15*#</td>
<td>+49.15</td>
<td>+82.94</td>
</tr>
<tr>
<td>Alpha</td>
<td>4.56 ± 0.13</td>
<td>4.86 ± 0.14*</td>
<td>5.02 ± 0.17*#</td>
<td>+33.86</td>
<td>+57.28</td>
</tr>
<tr>
<td>Beta</td>
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<td>4.89 ± 0.16</td>
<td>4.86 ± 0.13</td>
<td>-3.24</td>
<td>-6.54</td>
</tr>
<tr>
<td>Gamma</td>
<td>1.41 ± 0.09</td>
<td>1.35 ± 0.12</td>
<td>1.40 ± 0.11</td>
<td>-5.92</td>
<td>-0.99</td>
</tr>
<tr>
<td><strong>Total power</strong></td>
<td>5.50</td>
<td>5.62</td>
<td>5.69</td>
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<td></td>
</tr>
<tr>
<td><strong>Power ratio (%)</strong></td>
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<td>Delta</td>
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<td>0.99</td>
<td>1.02</td>
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<td>+20.82</td>
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<td>2.64</td>
<td>3.02</td>
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<td>46.66</td>
<td>51.09</td>
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<td>43.48</td>
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<td>Gamma</td>
<td>1.67</td>
<td>1.39</td>
<td>1.37</td>
<td>-16.47</td>
<td>-18.06</td>
</tr>
</tbody>
</table>

*Table 5.14: Experiment 2 overall spectral power and ratios. Mean ± standard deviation. * Spectral power is significantly different from that in Baseline condition. # Spectral power is significantly different from that in eRug condition. p<.05.*
Control revealed that theta increased by 34% ($F_{1.67,432.4}=369.2$, $p<.05$, $W(2)=.65$, $\varepsilon=.74$) and alpha increased by 23% ($F_{1.76,412.8}=464.73$, $p<.05$, $W(2)=.75$, $\varepsilon=.81$). This reveals that praying on the eRug seemed to have a greater impact on theta and alpha brain activity than praying without the eRug. Beta and gamma were not affected in the two conditions, Control and eRug, as compared to Baseline. The delta band changed during eRug while it did not during Control. Hence, the null hypothesis $H_3$, which stipulated that performance during eRug will be similar to Control, has been disproven. Power ratios were calculated for the five bands and showed an increase in delta, theta and alpha ratios accompanied by a drop in beta and gamma ratios.

Next, EEG data, using Log$_e$ power, were averaged in six regions: frontal lobe (AF8,F4,F8,AF7,F3,F7,FPz,Fz), central sulcus (C1,C2,C3,C4), temporal lobe (T3,T4), parieto central (CPz,CP1,CP2), parietal lobe (P3,P7,P4,P8,Pz), and occipital lobe (Oz,PO3,PO4). Table 5.15 shows the mean and standard deviation of different lobes.

In the frontal lobe, the eRug increased delta by 74% ($F_{2,24}=101$, $p<.05$), theta by 75% ($F_{2,24}=98.3$, $p<.05$) and alpha by 25% ($F_{2,24}=71.4$, $p<.05$) above the Baseline condition while it decreased beta by 16% ($F_{2,24}=68.2$, $p<.05$) and gamma by 17% ($F_{2,24}=59.7$, $p<.05$) below Baseline. Similarly, the Control condition increased delta by 70% ($F_{2,24}=68.7$, $p<.05$), theta by 54% ($F_{2,24}=84.9$, $p<.05$), alpha by 17% ($F_{2,24}=86.3$, $p<.05$) above Baseline, while beta decreased by 13% ($F_{2,24}=92.4$, $p<.05$) and gamma by 22% ($F_{2,24}=95.3$, $p<.05$) below Baseline. The eRug scores were statistically higher than Control in the theta and alpha bands: theta was higher by 14% ($F_{2,24}=82.1$, $p<.05$) and alpha was higher by 7% ($F_{2,24}=75.3$, $p<.05$).
Table 5.15: Experiment 2 regional spectral power and ratios. Mean ± standard deviation.

<table>
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<tr>
<th>Region</th>
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<th>Control</th>
<th>eRug</th>
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<td>Frontocentral</td>
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<td>Theta</td>
<td>Alpha</td>
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<td>Baseline</td>
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<td>1.56 ± 0.23</td>
<td>4.54 ± 0.18</td>
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<td>5.34 ± 0.14*</td>
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<td>1.41 ± 0.19*</td>
<td>2.74 ± 0.11*#</td>
<td>5.69 ± 0.13*#</td>
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<td>Central Sulcus</td>
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<td>Theta</td>
<td>Alpha</td>
</tr>
<tr>
<td>Baseline</td>
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<td>1.52 ± 0.21</td>
<td>4.39 ± 0.13</td>
</tr>
<tr>
<td>Control</td>
<td>0.79 ± 0.13</td>
<td>1.54 ± 0.15</td>
<td>4.43 ± 0.20</td>
</tr>
<tr>
<td>eRug</td>
<td>1.41 ± 0.22*</td>
<td>2.46 ± 0.18*</td>
<td>4.91 ± 0.17</td>
</tr>
<tr>
<td>Temporal</td>
<td>Delta</td>
<td>Theta</td>
<td>Alpha</td>
</tr>
<tr>
<td>Baseline</td>
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<td>1.45 ± 0.12</td>
<td>5.04 ± 0.21</td>
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<tr>
<td>Control</td>
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<td>5.41 ± 0.16*</td>
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<tr>
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<td>2.46 ± 0.18*</td>
<td>4.91 ± 0.17</td>
</tr>
<tr>
<td>Parieto Central</td>
<td>Delta</td>
<td>Theta</td>
<td>Alpha</td>
</tr>
<tr>
<td>Baseline</td>
<td>0.62 ± 0.22</td>
<td>1.54 ± 0.17</td>
<td>4.59 ± 0.16</td>
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<td>0.83 ± 0.27</td>
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<td>1.58 ± 0.16</td>
<td>4.61 ± 0.17</td>
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<tr>
<td>Parietal</td>
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<td>Theta</td>
<td>Alpha</td>
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<tr>
<td>Baseline</td>
<td>0.85 ± 0.17</td>
<td>1.72 ± 0.14</td>
<td>4.49 ± 0.12</td>
</tr>
<tr>
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<td>1.41 ± 0.24*</td>
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<td>4.92 ± 0.21*</td>
</tr>
<tr>
<td>eRug</td>
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<td>2.52 ± 0.28*</td>
<td>5.34 ± 0.27*</td>
</tr>
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<td>Alpha</td>
</tr>
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<td>4.31 ± 0.21</td>
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<td>eRug</td>
<td>0.61 ± 0.11</td>
<td>1.67 ± 0.24</td>
<td>4.73 ± 0.15*</td>
</tr>
</tbody>
</table>

Table 5.15: Experiment 2 regional spectral power and ratios. Mean ± standard deviation. * Spectral power is significantly different from that in Baseline condition. # Spectral power is significantly different from that in Control condition. p<.05.

In the temporal lobe, the eRug increased delta by 120% (F2,24=58.7, p<.05) and theta by 69% (F2,24=92.5, p<.05) as compared to Baseline. The eRug did not have an effect on the other bands, as compared to Baseline. The Control increased alpha by 7% (F2,24=85.3, p<.05) above Baseline and did not have effect on any of the other bands.

In the parietal lobe, the eRug and Control had a similar statistical significant effect as compared to Baseline. The eRug caused an increase in delta by 63%, (F2,24=99.7, p<.05), theta by 46% (F2,24=61.6, p<.05) and alpha by 18% (F2,24=68.4, p<.05). No change happened in the beta and gamma bands in the parietal lobe.

In the occipital lobe, only the eRug had a statistically significant change; an increase in the alpha band by 10% (F2,24=74.9, p<.05) as compared to Baseline and an increase in the
beta band by 12% (F_{2,24}=60.3, p<.05) as compared to Baseline.

Next, the magnitude of the difference in differences between statistically significant Baseline, Control, and eRug values was investigated. Table 5.16 lists the sum of the differences and the absolute differences between scores per lobe for the five bands. Control-Baseline is the difference between Control and Baseline, eRug-Baseline is the difference between eRug and Baseline, and eRug-Control is the difference between eRug and Control. An ANOVA test was conducted between the three scores. Statistical analysis showed a significant effect (F_{1,12}= 8.12, p<.05). Post hoc analysis revealed two significant pairs: Control-Baseline/eRug-Baseline (p<.05) and eRug-Baseline/eRug-Control (p<.005). The significant difference between Control-Baseline and eRug-Baseline indicates that the change during eRug, from Baseline, is not similar to the change during Control from Baseline. Analysis also revealed that eRug-Baseline is significantly different from eRug-Control, thus the change during eRug is significantly different from Control and also from Baseline. Investigating these differences further involves determining; 1) whether the polarity of changes agree with each other – both being positive or both being negative, 2) whether the changes are parallel to each other or not – when one increases, the other increase and the reverse, and 3) determining the largest impact of the eRug and Control. Comparing the individual differences of Control-Baseline/eRug-Baseline and eRug-Baseline/eRug-Control shows that the differences agree in polarity in 85% of the cases. Opposite polarity was recorded only between eRug-Baseline/eRug-Control. In the frontal lobe, while eRug did lower gamma wave power, as compared to Baseline, gamma was still slightly higher than Control. In the parietal lobe, while eRug increased delta as compared to Baseline, the increase was still lower than that
induced during Control. Table 5.16 also reveals that the power change induced during eRug increased or decreased in a parallel manner to that of Control. For example, in the lower frequencies (delta, theta, alpha) of the frontal lobe, eRug and Control increased power – though eRug seemed to cause a greater increase. Similarly, eRug and Control decreased beta power – though eRug seemed to cause a greater decrease.

To investigate the cumulative effect of each condition, the difference, in each band, was summed (see second last column in Table 5.16). In eRug-Baseline case, the change was larger in magnitude than Control-Baseline in all the lobes that witnessed a statistically significant change: frontal (1.84 versus 1.23), temporal (1.79 versus 0.37) and parietal (2.19 versus 1.66). Summing the absolute changes in every lobe in each band (see last column in Table 5.16) reveals that the largest change (4.02) was in the frontal lobe, in
eRug-Baseline, followed by Control-Baseline (3.21). Thus eRug’s largest impact is in the frontal lobe. The third largest change is in the parietal lobe in eRug-Baseline, with an increase of 32% over Control-Baseline difference (2.19 versus 1.66 respectively). This increase is entirely in the lower frequency which indicates that the eRug decreased the user’s sense of awareness further.

**Coherence Analysis**

EEG coherence was computed for all 300 intra-hemispheric\(^{74}\) and inter-hemispheric\(^{75}\) pair wise combinations of the 25 channels in each of the 5 frequency bands. A repeated-measures ANOVA was used to analyze EEG coherence. Post hoc t-tests were carried out where appropriate. Out of the 1500 pairs (300 combinations x 5 spectra), 33 pairs (Figure 5.12) were found to show statistically significant coherence changes (p <.05) in three bands: delta, theta and alpha. Hence, the null hypothesis H\(_4\) can be rejected for some factors. In the delta band, *Control* condition had 13 significant pairs; 8 left-right pairs, 2 left-left pairs, 2 left-center pairs and 1 right-center pair. *eRug* had 7 significant pairs; 5 left-right pairs and 1 left-center pair, and 1 right-center pair. Five pairs were common between *Control* and *eRug* in the delta band.

In the theta band, *Control* had 17 significant pairs; 9 left-right pairs, 4 right-right pairs, 2 left-left pairs, 2 left-center pairs. *eRug* had 22 significant pairs; 5 left-right pairs, 10 right-right pairs, 3 left-left pairs, and 4 left-center pairs. Nine pairs were common between *Control* and *eRug* in the theta band.

In the alpha band, *Control* had 21 significant pairs; 7 left-right pairs, 7 right-right pairs, 3 left-left pairs, 3 left-center pairs, and 1 right-center pair. *eRug* had 17 significant pairs; 5

\(^{74}\) Across the two brain lobes – left and right.

\(^{75}\) Within the same brain lobe.
left-right pairs, 10 right-right pairs, 1 left-left pair, 1 left-center pairs and 1 right-center pair. Fourteen pairs were common between Control and eRug in the alpha band. Five pairs in the frontal lobe connecting left and right hemispheres (AF7-AF8, AF7-F8, F7-AF8, F7-F8, F3-F4) witnessed significant change in Control and eRug conditions in all three bands. Out of the 33 significant pairs, 14 pairs were common between eRug and Control in one or more band. Table 5.17 lists the individual coherence values.

Table 5.18 lists the average percentage values per lobe. Mean coherence increased in frontal lobe in the three bands, with the highest increase in the theta band. The eRug induced a further increase than Control in the delta and theta bands. The central connected pairs also showed coherence increase but in the theta and alpha bands only – with the eRug increasing the coherence further than the Control. In the parietal lobe, coherence decreased in the theta and alpha bands. The eRug induced a further decrease as compared to Control in both bands. In the temporal lobe, the coherence increased in Control while it did not change significantly between eRug and Baseline. In the occipital lobe, the coherence increased significantly in eRug while it did not change significantly between Control and Baseline.
Figure 5.12: Experiment 2 pairs with significant change in coherence from Baseline. Top row shows Control condition. Bottom row shows eRug condition. (a) Delta waves pairs. (b) Theta waves pairs. (c) Alpha waves pairs.
<table>
<thead>
<tr>
<th>Lobe</th>
<th>Pairs</th>
<th>Delta</th>
<th>Theta</th>
<th>Alpha</th>
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</thead>
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<tr>
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<tr>
<td></td>
<td></td>
<td>+66%</td>
<td>+73%</td>
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<tr>
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Table 5.17: Experiment 2 electrode pairs with statistically significant change. Values shown are coherence mean ± standard deviation. Grayed areas did not show significance. * Coherence is significantly different from that in Baseline condition. # Spectral power is significantly different from that in Control condition. p<.05.

<table>
<thead>
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<th>Lobe</th>
<th>Pairs</th>
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<th>Theta</th>
<th>Alpha</th>
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<tr>
<td></td>
<td>PO4-F4, PO4-P4, PO4-P8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-1%</td>
<td>+64%</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.18: Experiment 2 coherence % change per region. Values shown are average percentage increase (or decrease) in coherence – as compared to Baseline. Grayed areas did not show significance between Baseline, Control, and eRug.
5.6.8 Discussion

Power Analysis

Considering the overall power distribution and ratios (see Table 5.12), the difference between using the eRug and Control were in the lower three bands; delta, theta and alpha. In the delta band, while the Control did not differ from Baseline, eRug increased the delta power by 46%. The trend of shifting the power to lower frequencies is even more obvious with theta and alpha. In the theta band, eRug almost doubled the increase in power from 49% in Control to 82%. In the Alpha band, eRug again almost doubled the increase in power from 33% in Control to 57%. Beta and gamma did not change between Control, eRug and Baseline.

Power ratios confirm the observation that lower frequencies are dominating. The ratios of delta, theta and alpha to total power, increased in Control and continued increasing further in eRug. On the other hand, the ratios of beta and gamma decreased in Control and continued increasing further in eRug.

Considering the per lobe power distribution (see Table 5.15), a more complex picture emerges. Four lobes witnessed a statistically significant change: frontal, temporal, parietal and occipital. In the frontal lobe, the trend of increasing the power of lower frequencies and decreasing power of higher frequencies was clear. While Control and eRug had the same impact on delta power by increasing it by 70%, they differed in how they affected the theta and alpha bands. eRug increased theta power 14% more than Control and increased alpha power by 7% more than Control. Thus eRug induced more theta and alpha in frontal lobe than Control could. In the higher bands, beta and gamma, Control and eRug had the same lowering impact on power as compared to Baseline, 16%
and 22% respectively. The dominance of lower frequencies in the frontal lobe causes a relaxing condition (Johansson & Uneståhl, 2006). Since the lower frequencies recorded during eRug was statistically different from those recorded during Salah, then one can conclude that eRug made the participant further relaxed.

In the temporal lobe, eRug’s delta, theta, and alpha readings were statistically significant from Baseline but Control was not. In the beta band, both Control and eRug had significant readings but opposite ones. Control increased beta power by 7% while eRug decreased it by 3%. During eRug, the participants read the verses from the screen, and hence, alpha did not change from Baseline. Again, results show that higher frequencies subsided to lower frequencies which indeed increased in the eRug condition; delta increased by 98% and theta increased by 52%.

In the parietal lobe, eRug and Control had a similar effect. They both increased delta by ~65%, theta by ~46% and alpha by ~19%. Beta and gamma did not differ from Baseline. The parietal lobe is involved in detecting orientation and generating a sense of awareness of space (Kusonoki & Goldberg, 2003; Goldberg, Bisley, Powell, & Gottlieb, 2006; Avillac et al., 2005; Zhang et al., 2004). Since eRug did not change the participants’ sense of space and orientation, as compared to Baseline, then one can conclude the eRug was not distractive. Otherwise, the participant would have had an increase sense of space and orientation.

In the occipital lobe, only eRug caused an increase in alpha band power by 10% and an increase in beta band by 12%. The occipital lobe is primarily responsible for vision related tasks (Orrison, 2009). Previous research on reading tasks has shown a systematic increase in spectral power as reading task complexity increased (Krausse et al. 1998;
Bizas et al., 1999). Hence, the recorded changes could be attributed to reading the Quran from a screen during the eRug condition.

Results show that using the eRug did not drastically change the performance from that recorded without the eRug. Instead, the effect of Salah has been magnified by the usage of the eRug in the frontal lobe. The parietal lobe recording did not change between Salah and eRug. The temporal and occipital lobes have shown different results, between the two conditions, due to the nature of the tasks involved. Hence, the null hypothesis $H_3$ which speculated that the power spectrum will be similar in Salah on the eRug compared to Salah without the eRug has been invalidated. There are similarities and there are also differences. Most importantly, the similarities exist in the two lobes responsible for intelligence (frontal lobe) and developing a sense of awareness of space (parietal lobe).

Hence, once can conclude that the eRug does not negatively affect the ritual quality.

Considering the difference in difference between Control-Baseline, eRug-Baseline, and eRug-Control (see Table 5.16); although the eRug differences are statistically different from Control, the eRug’s effect is not contradictory to the Control’s effect. The eRug had a parallel but stronger effect compared to Control.

**Coherence Analysis**

Coherence analysis revealed a complex web of pairs interacting with each other. Thirty-three pairs exhibited significant change in the three bands: delta, theta and alpha. Coherence analysis revealed that introducing a screen did not degrade the concentration and attenuation of the participants. Figure 5.13 shows the pairs that witnessed the same statistically significant change in both conditions. Out of the 33 pairs that showed statistically significant change, 14 pairs were common in both conditions, seven of which
are in the frontal lobe, the region responsible for concentration (Beaumont, 2008; Orrison, 2009). Salah with eRug still demonstrated the remarkable left to right coherence as Salah without eRug.

Figure 5.13: Experiment 2 pairs common between Control and eRug Conditions. Top row shows Control. Bottom row shows eRug. (a) Delta waves pairs. (b) Theta waves pairs. (c) Alpha waves pairs.

Figure 5.14 shows pairs that had a statistically significant change and are unique between conditions. Four sets of pairs could be identified, temporal pairs, occipital pairs, parietal-frontal pairs and frontal pairs. The first set (T3-F3, T3-F7, T3-Fz, T3-P4, T3-Pz, T3-T4,
T4-F3, T4-Fz) are all related to recalling the Quran verses\textsuperscript{76} and they did not appear in Salah with eRug since participants were reading from the screen. The second set (PO3-F3, PO3-P7, PO4-F4, PO3-Oz, PO4-Oz, PO4-P4, PO4-P8) involves the occipital lobe. Three pairs, PO3-F3, PO3-P7, and PO4-F4 are between parietal-occipital and frontal which suggests that these pairs are communicating visual information to the processors in the frontal lobe. The fact that these pairs did not show significance during Salah without eRug provides some evidence that they are somehow related to reading from screen. All pairs are also in the theta band which conforms to previous research which showed theta band coherence increase during reading text (e.g. Weiss & Mueller, 2003). The third set involves parietal-frontal connections (P8-F8, P8-F4, P8-AF8) where the same pattern of decreasing coherence between frontal and parietal lobes occurs. This likely indicates that the participants were immersed in the ritual and disconnecting further from the surroundings. The fourth set (F3-Fz, F4-Fz, F4-AF8, F4-F8) involves connections within the frontal lobe which suggests that the participants were concentrating further in the ritual.

\textsuperscript{76} Section 5.5.8 includes references to previous works which documented EEG coherence patterns during the recall of textual information.
Experiment 2 uncovered the immediate impact of using the eRug on some of the brain areas. However, it is not clear whether that change had any effect on the concentration and attenuation of the practitioner over the long term or not. The next section contains a description of a longitudinal study focusing on the long term impact of the eRug.
5.7 Longitudinal Study

5.7.1 Subjective Evaluation

The eRug main design goal is to support the average user in enabling a better performance of Salah. Although the EEG studies showed that the user’s neuro-physiological signature is better in Salah with the eRug than without, it does not necessarily imply the existence of a long term impact. The goal of this next study is to investigate if users’ subjective impressions of their own performance of Salah after using an eRug over an extended period.

There has been several instruments devised to measure the individual’s satisfaction with their own life, such as the quality of life index (Costanza et al., 2008), or the life satisfaction index (White, 2007). However, none of these is usable for the eRug evaluation because of the restricted role religion plays in an average user’s life. For example, an average user might face a calamity during the evaluation period and that, in turn, affects her own perception of life quality. In the case of religious users, the individual may turn to her religion and find solace in the religious interpretation of uncontrolled events, and hence would not consider such event as affecting life quality. To avoid the impact of such external factors, there was a need for an instrument that is based on a model that captures the Salah experience and nothing else. Csíkszentmihályi (1975) proposed flow theory to explain the engagement of individuals in activities such as playing games, studying, and learning music. This theory seemed to fit the needs of the eRug study based the author’s own experience with Salah, being a ritual with many characteristics that are often associated with flow. The following sections presents an

77 Average here refers to a moderate score on the MRPI scale.
overview of flow theory, followed by a discussion of applicability to Salah, and concludes with flow measurements techniques.

### 5.7.2 Flow Theory

“Flow” is the term commonly used to describe a mental state in which a person is fully immersed in what he is doing, and which is characterized by a feeling of energized focus, full involvement, and successful processing of the activity concerned. Csíkszentmihályi, the psychologist who pioneered this concept, calls it "being completely involved in an activity for its own sake. The ego falls away. Time flies. Every action, movement, and thought follows inevitably from the previous one. Your whole being is involved" (Csíkszentmihályi, 1990:24). He summarizes flow experiences as comprising nine elements; clear goals, concentrating and focusing, a loss of the feeling of self-consciousness, distorted sense of time, direct and immediate feedback, balance between ability level and challenge, a sense of personal control over the situation or activity, the activity is intrinsically rewarding, and absorption in the activity. Flow is defined in terms of skills and challenges. On a graph of skill versus challenge (Figure 5.15),

![Flow Theory Diagram](image_url)

**Figure 5.15: Csíkszentmihályi’s original single-channel model of flow – from (Csíkszentmihályi, 1975:56).**
Csíkszentmihályi described flow as the area between anxiety, where the task challenges the user’s skill to the extent that the user becomes anxious, and boredom, where the task presents no challenge to the user compared to her skill. Being in flow means being challenged enough but not to the extent that will divert attention away from the task at hand.

5.7.3 Applicability of Flow Theory to Salah

Flow theory could be used to evaluate the performance of a participant in Salah since the nine criteria identified by Csíkszentmihályi could apply as explained below;

Clear Goals

When a person experiences flow, his expectations and rules are discernible and goals are attainable and align appropriately with his skill set and abilities (Csíkszentmihályi, 1975). Similarly, believers in a religion are motivated by the religion’s interpretation of life and that of afterlife. There are two broad goals behind practicing Salah: to be empowered – by God – to live a good life, and the second is to attain paradise in the afterlife. Not only are these clear goals but they are also common among all practitioners.

Concentrating and Focusing

A person engaged in an activity will have the opportunity to focus and to delve deeply with a high degree of concentration on a limited field of attention (Csíkszentmihályi, 1975). Attention and concentration are vital in Salah. A Salah is thought to be invalidated, or even nullified, if it is performed without concentration. Practitioners are required to avoid any form of distraction before entering into Salah – whether it is
distraction to oneself or to other attending practitioners.\footnote{For example, many mosques have banners asking adherents to switch off cell phones.}

\textit{A Loss of the Feeling of Self-consciousness}

In flow experience, action and awareness merge and the user is completely absorbed in the activity (Csíkszentmihályi, 1975). Salah exhibits such merge due to the Islamic teachings of the metaphysical dimension associated with the practice. Muslims believe that from the instance Salah commences, and God looks the practitioner in the face (AlBukhari, 846/2002, #1899). Consequently, Muslims are taught, since childhood, to disconnect from the physical world during prayer (Mababaya, 2006) – as instructed by the Quran (Quran, 2:44-45).

\textit{Distorted Sense of Time}

In flow experience, a person’s subjective experience of time is altered. Similarly, in Salah, the author’s experience is that practitioners often report that they lose track of time. Practitioners often cannot accurately estimate how much time they actually spent in prayer.

\textit{Direct and Immediate Feedback}

In flow experience, successes and failures in the course of the activity are apparent so that behavior can be adjusted as needed. In Salah, the practitioner is required to monitor her performance and compensate for errors or slips using an apologetic gesture. In group prayer, if the Imam\footnote{Imam here refers to someone who leads Salah since group prayer must be done with a leader.} commits a mistake, other practitioners are allowed to provide him with feedback and they all perform the apologetic gesture.

\textit{Balance Between Ability Level and Challenge}

Salah is simple to perform which enables all believers regardless of their age, sex and
physical capabilities to practice. Advanced practitioners still perform the same rituals as novice ones. The challenge to an advanced practitioner in Salah is to increase the duration and/or frequency of the ritual. As time elapses, a practitioner’s mental focus decreases and the chance of performing a mistake – that would nullify the ritual – increases; that is why, advanced practitioners still find the practice challenging.

*A Sense of Personal Control over the Situation or Activity*

Islamic tradition gives the practitioner the freedom to perform Salah at any specific time during a pre-allocated interval. On average, each one of the five daily Salah has an open time slot of 3 hours\(^{80}\). This gives the practitioner a sense of control, because she can commence the prayer at her most convenient time. The time to be spent in Salah is also left to the practitioner. Hence, the practitioner can decide how long to pray, based on their own experience and circumstances. This is likely to contribute to the practitioner’s ability to achieve a state of mental flow while praying, since she initiates the action and has control on the time it will take her to complete. Furthermore, the practitioner can interrupt any of the gestures\(^{81}\) to move to the next one when she feels satisfied with her performance of that gesture. Although Salah has mandatory verses that must be recited, space within the Salah is left for optional verses to be chosen by the practitioner, which also enhances the feeling of control.

*The Activity is Intrinsically Rewarding*

In flow experience, users do not complain about the activity being performed. Instead, users often reflect back on the experience as being associated with effortlessness of action. For many practitioners, Salah is associated with a feeling of accomplishment and

\(^{80}\) Because Islamic calendar is lunar based, this varies from 6 hours for some prayers in some parts of the world to 1.5 hours in other.

\(^{81}\) Illustrated in Figure 2.1.
reward. Practitioners often report feelings of calmness during and immediately after the ritual. These feelings last for a very short duration after the conclusion of Salah and practitioners often attribute it to the practice itself. The EEG evaluation of Salah provided some evidence on some of the changes that happen in the brain and could be considered physiological indicators relating to the reported feelings.

Absorption in the Activity

During flow, with the focus of awareness narrowed down to the activity itself; action and awareness merge (Csikszentmihalyi, 1975). Perhaps one of the striking examples of absorption in the activity is the Taraweeh Salah during the month of Ramadan. Taraweeh, whose literal meaning is to have enjoyment – being in the presence of God – commences only two hours after breaking the daily fasting from food and drink. This type of optional Salah ritual, as witnessed by the author of this research, typically lasts two to four hours with rarely anyone complaining about the extended periods of time spent. The noticeable diminishing of physical exhaustion is an indication of the adherents being absorbed in their prayers.

5.7.4 Review of Flow Measurement Instruments

Although the flow definition – being an experience between boredom and anxiety – might have captured the essence of the term, yet such broad definition is difficult to operationalize and measure. Consequently, evaluating flow has been inconsistent in the literature. Thirteen constructs have been identified as representative of flow: degree of arousal (Ellis, Voelkl, & Morris, 1994), perception of challenge (Csikszentmihalyi &

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82 See Section 5.5
Csikszentmihalyi, 1988), feeling of control (Csikszentmihalyi, 1977), exhibiting exploratory behavior (Trevino & Webster, 1992), focusing attention (Csikszentmihalyi, 1977), perceived involvement in the activity (Csikszentmihalyi, 1977), experiencing playfulness (Trevino & Webster, 1992), positive affect (Privette & Bundrick, 1987), matching different skill levels with users abilities (Csikszentmihalyi & Csikszentmihalyi, 1988), telepresence (Hoffman & Novak, 1996) and experiencing time distortion (Lutz & Guiry, 1994). Table 5.19 shows the constructs measured by each of 16 different studies. As not all constructs are applicable to every activity, a relevant subset is selected based on the task at hand. Researchers have used a combination of two or more of the following techniques to measure flow: subjective self-reporting, observation, physiological

measures, indirect task assessment, and attention and concentration tests. Following is a description of each accompanied by a discussion of applicability to religious rituals in general and eRug evaluation;

*Subjective Self-reporting*

A widely used evaluation technique which either involves administering a questionnaire after the event to elicit ratings of user feelings, conducting interviews, or focus groups. According to Csíkszentmihályi’s early flow model (Figure 5.15) a challenge/skill ratio of 1:1 should indicate flow. Hence, one solution has been to use a measure of the balance between the challenge of an activity and the participant's perception of their skill to carry out that activity. The perception of these challenges and skills has been described as “theoretically, the most meaningful reference point for the presence or absence of flow” (Massimini & Carli, 1988:261). Even if researchers used a model with more than three channels, they would normalize a challenge/skill plot to the individual's average challenge/skill value over the extended period of the study.

Some researchers view flow as both a process that an individual goes through as well as being a state. For example, Pearce et al. (Pearce, Ainley, & Howard, 2005) used two questionnaires; a short version (Figure 5.16) administrated several times during intermissions in an experiment’s trial. The goal was to measure participant’s perceived skill as well as challenge. In addition, a longer questionnaire (Figure 5.17) was administrated at the end of the experiment to measure the overall flow experience from the user perspective.
A criticism of self-reporting is that it relies on the users to accurately recalling and articulating their feelings after the event, and thus may be inherently unreliable. As a result, researchers often combine subjective self-reporting with other, more quantitative techniques. In addition, many respondents find it challenging to answer questions related to flow (Chen, Wigand, & Nilan, 1999). A third disadvantage is that all types of self-reporting methods suffer from low evaluative bandwidth in that few data points are provided per unit of time since the technique only generates data when a question is asked. Consequently, subjective reporting should be used with caution while attempting to evaluate the impact of a system on a religious ritual. Since the current state of knowledge about the nature of spiritual experience is limited, the questions used to measure flow should be carefully formulated to avoid false positives and negatives. It
was these disadvantages that made conducting EEG experiments essential to be able to confirm the findings of the subjective evaluation of the eRug.

A variation on the self-report theme involves using a video situated recall methodology (Lyle, 2003). Users are again encouraged to recall their feelings retrospectively, but this is prompted by watching a video replay of the activity. The assumption is that a user will be re-immersed in the experience via the video, leading to a more accurate recall of thoughts and feelings (Bentley, Johnston, & von Baggo, 2005). This non-intrusive approach could be more suitable to religious ritual evaluation, especially if the ritual consists of sequence of movements and recitations which the user might not be able to reflect on accurately unless seen via video. However, one major concern with this approach is the impact on the user performance, and consequently flow. Religious rituals are highly personal experiences and it is not clear what impact will video recording the ritual has.

*Observation*

Another common approach has been to employ observational methods using video, typically combining interpretation of think-aloud commentary and coding of cues of emotion, such as facial and verbal expressions, body language and gesture (Mandryk, 2004). However, attempts to interrupt the activity to gauge the user’s feelings as they occur are likely to contaminate the data as the intrusive nature of such an approach can also alter the user emotional and mental state and negatively affect the flow experience being discussed. In addition, for a religious ritual, employing think-aloud is not feasible due to the restrictions placed by religion on engaging in external activities during rituals. Furthermore, requiring the user to comment, during the practice, sabotages the user
engagement.

**Physiological Measures**

Researchers have used a multitude of physiological measures in attempting to gauge if a user is experiencing flow or not. Measures utilized in flow evaluation include; facial expressions, blood volume pulse, heart rate, blushing-assessed with a photoplethysmograph, and constriction and expansion of the pupil. However, these different physiological measures do not correlate well with one another (Leary, 1986). Furthermore, such low resolution measures are only indicative of stimulation or arousal and it can generally be difficult to distinguish between different user states. For the purpose of eRug evaluation, the first set of experiments were performed using EEG and hence using physiological measures to evaluate flow was deemed unfavorable due to the need to use a different evaluation technique.

**Indirect Task Assessment**

Researchers, realizing that flow is hard to measure, resorted to techniques from psychology concerned with evaluating the indirect impact of a task. One such technique is the Implicit Association Test (IAT), which is based on the assumption that judgments can be activated automatically, outside the respondent’s conscious awareness (Greenwald, McGhee, & Schwartz, 1998). Participants are asked to respond as quickly as possible to words that signify the attitude object and words with positive or negative valence. For example, when measuring implicit attitudes toward Muslims, the attitude object may be represented by family names recognized as belonging to a Muslim, for example, ‘Mohamed’ versus ‘John’, and the valenced words by common positive or negative concepts (e.g. ‘Terrorist’ vs. ‘Peaceful’). Prejudiced individuals would therefore
be expected to respond more quickly to combinations of Muslim names with negative words than to combinations of Muslim names with positive words, and they should show the reverse pattern for white names. One advantage of IAT is that it tends to be virtually uncorrelated with corresponding explicit measures (Greenwald, McGhee, & Schwartz, 1998); indicating that it may indeed measure a different, more internal, type of attitude. Hence, an IAT test that associates religion-specific concepts and the flow experience could indirectly reveal the degree of user engagement.

Another indirect task assessment involves asking users how long they feel that they have spent on an activity. Csikszentmihályi (1990) noted that users in flow have distorted sense of time. Consequently, the reported estimate of the activity duration could be used to judge on the presence or absence of flow (Cutrell, Czerwinski, & Horvitz, 2001). One disadvantage of this technique is that tasks that were either too hard or too easy would result in an overestimation of the time passed. For the purpose of eRug evaluation, this technique is unsuitable because time cannot be used to judge the quality of the experience. Given that the eRug could be used to read pages from the Quran that users do not memorize, users might spend more time reading those pages than what they typically spend.

*Attention and Concentration Tests*

One of the characteristics of flow is that the user will be attentive to the task at hand. Hence, researchers tried measuring attention and concentration as an indirect indicator of flow. Traditionally, attention is measured using the Stroop test (Stroop, 1935), or the Dot-Probe test (Amin, Constable, & Canli, 2004). Both of these tests involve displaying two stimuli; a target stimulus and a distracter stimulus. The user is required to focus on the
target and avoid interference from the distracter stimulus. Researchers measure attention based on indirect measures of changes in reaction time, or stimulus detection and interference. However, Stroop and Dot-probe tests are unsuitable because they will obstruct the flow experience.

Instead, a third new technique involving the monitoring of neck muscles has been proposed. Chapman and Corneil (2011) found that neck muscles are recruited during reflexive covert orienting, even in the absence of eye movements. Monitoring muscle activity in the neck could provide a clue to whether the user is paying attention or not.

There are two techniques currently being used to indirectly measure concentration, namely; questionnaires and physiological indicators. A flow questionnaire would include queries about the user’s self perceived concentration level, energy and motivation, and details about performed tasks to check if user actually did concentrate throughout task. Again, a criticism of such self-reporting technique is that they rely on the user accurately recalling and being able to articulate their feelings after the event, and thus may be inherently unreliable.

Physiological indicators include galvanic skin response (GSR) and magnetic resonance imaging (MRI). GSR is a method of measuring the electrical resistance of the skin. A high level of cortical arousal is associated with increased powers of reflection and focused concentration. A low level of cortical arousal is indicative of relaxation. Cortical arousal has a simple relationship to skin conductivity - arousal of the cortex increases the conductivity of the skin and conversely, a drop in arousal causes a drop in skin conductivity. Another recently proposed technique in measuring concentration is using fMRI scanning (US patent 5460184). The process involves monitoring cerebral blood
oxygenation during alternating intervals of rest and specific task performance. The pattern of differences in blood oxygenation have been used to measure the degree of concentration. This is a promising technique but requires expensive and hard-to-setup hardware. Moreover, the constrained size of the MRI scanner compartment will not enable the user to perform rituals involving body gestures. Hence, using MRI scanning is not feasible to use for this study.

After reviewing the various instruments used in measuring flow, subjective evaluation was selected due to its versatility. However, existing flow questionnaires are more geared towards secular tasks. To achieve the goal of evaluating the long term impact of using the eRug in Salah, a tool was required to measure flow in Salah while taking into consideration the nature of the ritual and the teachings of the religion. The following section presents a discussion of how flow was measured in Salah.

5.7.5 Measuring Flow: Salah Flow Questionnaire

A Salah Flow Questionnaire (SFQ) was developed to measure the user’s perceived flow during Salah. The SFQ consists of fifteen questions, focusing on the participant’s perception of her flow experience during Salah. Thirteen questions used a 5-point Likert scale (Table 5.20) with five questions positively-keyed and eight questions negatively-keyed – whose values were reversed-scored before the statistical analysis. The remaining two questions were 1-10 rating scale questions in which the participants were asked to assess their concentration and attenuation. The questionnaire utilized five flow markers; focused attention (7 questions), involvement (four questions), time distortion (two questions), positive affect (one question) and intrinsic interest (one question). The SFQ is
included in Appendix J.

<table>
<thead>
<tr>
<th>ID</th>
<th>Question</th>
<th>Flow Marker</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>During Salah, I often have to repeat a Sura or Tahyat because I feel I recited it mechanically.</td>
<td>Focused Attention</td>
</tr>
<tr>
<td>2</td>
<td>After Salah, I am sometimes not sure about the actual number of steps I made.</td>
<td>Focused Attention</td>
</tr>
<tr>
<td>3</td>
<td>After Salah, I sometimes feel guilty due to my performance.</td>
<td>Focused Attention</td>
</tr>
<tr>
<td>4</td>
<td>I have to repeat a Salah after performing it because I feel it was not performed adequately.</td>
<td>Focused Attention</td>
</tr>
<tr>
<td>5</td>
<td>I often make mistakes during Salah.</td>
<td>Focused Attention</td>
</tr>
<tr>
<td>6</td>
<td>I feel agitated while attending a Jamaa Salah if the Imam recites a long sura (chapter).</td>
<td>Time Distortion</td>
</tr>
<tr>
<td>7</td>
<td>I feel exhausted attending a Jamaa Salah if the Imam recites a long sura (chapter).</td>
<td>Involvement</td>
</tr>
<tr>
<td>8</td>
<td>I lose sense of time while performing Salah.</td>
<td>Time Distortion</td>
</tr>
<tr>
<td>9</td>
<td>During Salah, interference (e.g. noise) would completely distract me and prevents me from concentrating in the practice.</td>
<td>Involvement</td>
</tr>
<tr>
<td>10</td>
<td>During Salah, I feel lifted and spiritual.</td>
<td>Positive Affect</td>
</tr>
<tr>
<td>11</td>
<td>I feel guilty if I do not perform Salah in the prescribed time.</td>
<td>Intrinsic Interest</td>
</tr>
<tr>
<td>12</td>
<td>I am satisfied with my concentration level during Salah.</td>
<td>Focused Attention</td>
</tr>
<tr>
<td>13</td>
<td>I am satisfied with my attenuation level during Salah.</td>
<td>Involvement</td>
</tr>
</tbody>
</table>

Table 5.20: SFQ and corresponding flow markers.

To test the reliability of the questionnaire, a test-retest method (Cohen, Swerdlik, & Phillips, 1996) was employed. Stratified sampling was adopted by first categorizing mosques, in the Greater Toronto area, according to the predominant ethnicity of the frequent attendees and religious affiliation. To maximize the likelihood of obtaining a representative sample, a total of 16 mosques were randomly selected and approached (two from each category). Sixty participants from seven mosques agreed to participate. A demographic questionnaire (Appendix I) was first administrated, followed by the SFQ. Since the questionnaire required the participant to release private information about their performance in Salah, the participants were reassured that the questionnaire was anonymous and individuals could not be identified. Five participants declined to complete the SFQ questionnaire for privacy concerns and withdrew from the survey.
Three months after the first administration, the same fifty-five participants were contacted to fill the SFQ again. Nine-participants declined or were unreachable; hence only forty-six refilled the questionnaire. Reliability assessment of SFQ was conducted following classical test theory principles (Novick, 1996). As a measure of internal consistency Cronbach's alpha was computed for each flow marker with more than one question in the SFQ. Pearson correlation coefficient was computed as a measure of temporal stability for each flow marker. Table 5.21 lists the five used markers with their corresponding Cronbach’s alpha and Pearson correlation. Results indicate acceptable internal consistency (George & Mallery, 2003) and acceptable temporal stability for the SFQ (Dowdy & Wearden, 1983). After confirming the reliability of the SFQ questionnaire, a study was launched to investigate the long term effect of the eRug.

<table>
<thead>
<tr>
<th></th>
<th>Internal Reliability</th>
<th>Test-retest Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Cronbach’s $\alpha$)</td>
<td>(Pearson’s r)</td>
</tr>
<tr>
<td>Focused Concentration</td>
<td>0.75</td>
<td>0.82</td>
</tr>
<tr>
<td>Involvement</td>
<td>0.72</td>
<td>0.76</td>
</tr>
<tr>
<td>Time Distortion</td>
<td>0.65</td>
<td>0.77</td>
</tr>
<tr>
<td>Positive Affect</td>
<td>-</td>
<td>0.71</td>
</tr>
<tr>
<td>Intrinsic Interest</td>
<td>-</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Table 5.21: SFQ Internal and test-retest reliability

5.8 eRug Longitudinal Study

5.8.1 Research Questions

It is hypothesized that there are two main functionalities the eRug provides that could contribute to a better performance; displaying Quran pages during prayer, and
automatically detecting errors. Displaying the Quran pages during prayer has the potential to enhance the overall experience since the user will be reading new pages with which he is not accustomed. Automatic error detection by the eRug might help alleviate stress experienced by the user due to over monitoring of his performance during a conventional prayer session.

The main research question of this longitudinal study was: will using the eRug for extended period help average users in enhancing their flow experience during Salah? Two secondary questions were; 1) which features of the eRug affected a change in usability after extended period? and 2) are there are possible enhancements that were not apparent from the EEG experiments?

5.8.2 Hypothesis

\( H_5: \) Using the eRug for extended period will not change the user flow experience.

5.8.3 Experimental Design

A within subject design was used in the study. The SFQ was administrated twice to all participants; before the onset of the study and a second time after four months.

A questionnaire about the eRug was also administrated at the end of study to elicit user feedback about the functionality, features and possible enhancements. The questionnaire (see Appendix J) consisted of nine 5-point Likert scale questions, two multiple choice questions, and three open ended questions for participants to provide their opinion of the best and worst feature in the eRug.
5.8.4 Participants

Thirty-four participants were initially recruited from a local mosque in Toronto. Each participant was given the MRPI Questionnaire (Appendix F). Two exclusion criteria were used; score on MRPI, and proximity of residence to nearest mosque. Since average Muslims were the target of this study, only participants who scored between 50% and 68% on the MRPI questionnaire were included in the study. Eight participants were disqualified, either because they scored lower or higher than the chosen range.

Islam encourages a Muslim to pray in a mosque if he lives in close proximity. This presented a problem for the current evaluation since it implied that the participants might not use the eRug as frequently as desired. The remaining participants were screened according to the proximity of their residence to a mosque. Those who lived in an area less than 2 km away from a mosque were disqualified. This exclusion criterion was used to ensure that the participant would use the eRug in most of the daily prayers.

Twenty male participants (M (age) = 30.3 yrs, SD = 4.1) were qualified. All participants were Sunni Muslims, had Arabic as their native language, and practiced Salah on a daily basis since childhood.

5.8.5 Procedure

Each participant received an hour of training on using the eRug. Participants were instructed to use the eRug in their mandatory and optional Salah for a period of four months. The eRug software was modified to track the number of prayers performed on the device. Participants were informed of this feature and they were reassured that the

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83 According to tradition, it is defined as a walking distance.
goal is not to judge them but for experimental purposes.

Before launching the study, each participant was asked to specify the suras\textsuperscript{84} from the Quran which he memorizes. To avoid introducing a bias in the study, a subset of the Quran which was not memorized by any of the participants was used with the eRug. 4518 verses out of the total of 6236 Quran verses were selected. Hence, all participants were exposed to the same verses throughout the four month period. Every two weeks, participants were contacted, via phone, to ensure their continuous usage of the eRug and to solve any problems that might have risen.

During the study, three eRug screens malfunctioned and the experiment for those participants was canceled due to a shortage in the LCD supply. Hence, the total number of participants who completed the study was seventeen.

5.8.6 SFQ Statistical Analysis

Questionnaire answers were first translated to an ordinal score: Strongly Agree=5, Agree=4, Neutral=3, Disagree=2, Strongly Disagree=1 – for the positive items and the reverse mapping was applied for the negative items.

A repeated measures analysis was performed on both questionnaire administrations uncovering statistically significant difference ($F_{1,220}=222.1$, $p<.005$). Next, a \textit{wilcoxon} paired test was performed to compare individual questions. The \textit{wilcoxon} test was chosen since it is inaccurate to assume the normality and homogeneity of variance for ordered categorical outcome when the ordinal outcome contains merely a small number of discrete categories. Twelve out of the thirteen questions showed a significant change as

\textsuperscript{84} Chapters.
illustrated in Table 5.22. Question 2 “After Salah, I am sometimes not sure about the actual number of steps I made” is the only one that did not show significance between pre and post usage of the eRug. This could be due to vagueness in the question statement. The phrase “After Salat” indicates that the participant already concluded the prayer and could have performed an apologetic gesture, which in turn compensate for any missing step. It is possible that participants misunderstood the question and thought that even after performing the apologetic gesture, they are being asked if they are still unsure about the number of steps performed. Figure 5.18 charts the scores for each question pre and post the study.

Multiple linear regression was used to estimate the magnitude of the effect of the covariates: age and usage frequency on the difference between pre-study and post-study scores. With seventeen participants and two covariates, the ratio of participants to variables is close to the recommended 10:1 (Brace, Kemp, & Snelgar, 2009) for conducting linear regression. The degree of association between the variables was estimated using correlation analysis.

Using the enter method, a significant model emerged (F_{2,14}=93.392, p<.0005). Adjusted R square = 0.769. The covariate Usage turned to be a predicator variable for the difference in scores – ScoreDif – with standardized beta coefficient of 0.777, p=.001. Age
<table>
<thead>
<tr>
<th>Question</th>
<th>Test</th>
<th>Mean (SD)</th>
<th>Z</th>
<th>r</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Pre</td>
<td>3.35 ± 0.6</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Post</td>
<td>3.70 ± 0.7</td>
<td>2.45</td>
<td>0.59</td>
<td>0.014</td>
</tr>
<tr>
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<td>Pre</td>
<td>3.35 ± 0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.58 ± 0.8</td>
<td>2.00</td>
<td>0.49</td>
<td>0.46</td>
</tr>
<tr>
<td>Q3</td>
<td>Pre</td>
<td>2.70 ± 0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.06 ± 0.5</td>
<td>2.45</td>
<td>0.59</td>
<td>0.014</td>
</tr>
<tr>
<td>Q4</td>
<td>Pre</td>
<td>3.82 ± 0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>4.18 ± 0.6</td>
<td>2.12</td>
<td>0.51</td>
<td>0.034</td>
</tr>
<tr>
<td>Q5</td>
<td>Pre</td>
<td>2.47 ± 0.9</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Post</td>
<td>3.30 ± 0.8</td>
<td>3.28</td>
<td>0.79</td>
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<td>Q6</td>
<td>Pre</td>
<td>2.06 ± 0.5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Post</td>
<td>2.59 ± 0.9</td>
<td>3.00</td>
<td>0.73</td>
<td>0.003</td>
</tr>
<tr>
<td>Q7</td>
<td>Pre</td>
<td>2.24 ± 0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.12 ± 0.6</td>
<td>3.64</td>
<td>0.88</td>
<td>0.0001</td>
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<tr>
<td>Q8</td>
<td>Pre</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Post</td>
<td>2.71 ± 0.9</td>
<td>3.36</td>
<td>0.81</td>
<td>0.001</td>
</tr>
<tr>
<td>Q9</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>2.53 ± 0.9</td>
<td>2.60</td>
<td>0.63</td>
<td>0.009</td>
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<td>1.76 ± 0.4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Post</td>
<td>2.77 ± 0.9</td>
<td>3.15</td>
<td>0.76</td>
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<td>Q11</td>
<td>Pre</td>
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</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.94 ± 0.8</td>
<td>3.40</td>
<td>0.82</td>
<td>0.001</td>
</tr>
<tr>
<td>Q12</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.01 ± 0.7</td>
<td>3.56</td>
<td>0.86</td>
<td>0.0001</td>
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<tr>
<td>Q13</td>
<td>Pre</td>
<td>1.88 ± 0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>2.41 ± 0.9</td>
<td>2.46</td>
<td>0.60</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Table 5.22: SFQ questions pre and post study scores.

Figure 5.18: SFQ pre and post question scores with standard error
was not a predicator for ScoreDif.

Pearson correlation analysis between ScoreDif, Age and Usage revealed the existence of a correlation between ScoreDif and Age (0.711, p=.001), ScoreDif and Usage (0.887, p<.0005), and Age and Usage (0.719, p=.001).

5.8.7 eRug Questionnaire Results

The questionnaire results are presented in Figure 5.19. Question 1 asked the participants to rate how difficult it was to learn to use the eRug. 88.3% it was either easy or very easy to learn and 11.7% said it is neither easy nor difficult. Question 2 asked how easy it was to use the eRug. 82.4% it was very easy or easy, 17.6% said it is neither easy nor difficult. Question 3 asked about how helpful the eRug was perceived. 64.7% chose it helped me a lot while 35.3% chose it somewhat helped me. Question 4 addressed the features of the eRug that might have inadvertently interfered with Salah; vibration, display of scripture, material and color of the eRug. 23.5% said the vibration interfered a bit. No other feature was noticed by the participants as interfering. Question 5 was concerned with the appeal of the GUI interface. Fifty-two percent said that the interface was appealing, while 47.1% said it is not appealing or unappealing. Question 6 asked about the difficulty of navigating the GUI, 58.8% said it is neither easy nor difficult, while 41.2% said it is easy. Question 7 asked the participant about the level of satisfaction with the eRug setup, 70.5% said they were satisfied while 29.5% said neutral. Question 8 asked about the satisfaction with the eRug functionality, 100% very satisfied or satisfied. Question 9 asked about the usefulness of the eRug, 64.7% said it is

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85 In terms of appearance, color scheme, and so forth.
useful, and 23.5% said it is very useful. Question 10 asked the participant if he would recommend the eRug to other Muslims. 29.4% chose I would highly recommend it, 47% chose I would recommend it sometimes depending on the person, and 23.5% said I would reluctantly recommend it. Question 11 offered the user five possible additions to the eRug and asked the participant to select all desired ones. Eighty-two percent chose larger screen, 58.8% chose colour-coded Quran text\textsuperscript{86}, 29.4% chose log and display of personal prayer performance, 41% chose Mecca locator. Twelve percent chose the other option under which they specified a request for phonetically correcting the recited verses. Out of five daily required prayers, three prayers are performed with loud voice. Practitioners, not trained in Quran recitation methods, mispronounce some of the words in the Quran. Participants, realizing the power of digital technology being now part of the rug, asked for a feature to help them with pronunciation. Question 12 gave a choice for the user between using the eRug and the traditional rug, all users said that they prefer the eRug. Question 13, an open ended question about which feature in the eRug the participants liked most, they all said using un-memorized Quran verses during Salah. Question 14, asked the participants about which feature they did not like most, 23.5% specified vibration and 35.3% said the sonar input is not accurate and they had to move their hand carefully up and down several times to invoke the scrolling or selection.

\textsuperscript{86} To assist in pronouncing words correctly.
Figure 5.19: eRug 3.0 questionnaire results.
5.8.8 Discussion

Regression analysis of the SFQ showed that only usage was a predictor of score difference which means that those who used the eRug could benefit more and vice versa. Correlation analysis showed that the older the participant, the more the eRug was used, while that the younger the participant, the less the eRug was used. In addition, the older the participant, the more the self-reported improved performance while the younger the participant, the fewer performance improvements occurred. Since regression analysis showed that Usage was the only predictor for the regression model, young participants may also benefit from the eRug if they use it more consistently.

In the SFQ, seven questions were asked about focused attention, four questions about involvement, two questions about time distortion, and one question about each of; positive affect and intrinsic interest. The results show that the participants experienced flow as their responses indicated affirmative answers for 12 of the 13 questions.

The eRug questionnaire showed that the device is generally easy to learn and use. The rendered functionality and interface were appreciated by the users. Several opportunities for enhancements were also revealed. The vibration needs to be reviewed in light of the participants’ feedback that when it is activated – it represented interference in prayer. One possibility is to empirically evaluate different vibration levels and techniques. Another major participant concern is the sensitivity of the sonar input. Several participants reported that the sonar was inaccurate in detecting their hand movement and they had to repeat the gesture several times before activating the interface or triggering selection in it. The questionnaire also revealed a potential new feature which to enable
the detection of incorrectly pronounced verses during Salah and provide means for auto correction.

5.8.9 Limitations

Participants’ ethnic and age homogeneity, being all Arab-speaking males in their late twenties or early thirties, is a limitation of this longitudinal study. Administering the questionnaire for two times only might also be considered as a limitation since participants might have been affected by external stimuli in the period the questionnaire was being administrated. A third limitation has to do with the SFQ; the SFQ questions were formulated to be activity focused; that is all questions that could be asked given the author’s knowledge of Salah were identified and next the corresponding flow marker was identified. This resulted in more questions about concentration than other inspected flow markers – such as immersion. Another approach could be to allocate the same number of questions for each flow marker used. This could result in a better flow inquiry. The challenge would then be is to also ask about all the important issues related to Salah.

5.9 Conclusion

In this chapter, the evaluation of the eRug was presented. Two physiological experiments and a longitudinal study had been conducted with the goal of determining the effectiveness of the device.

The first EEG experiment goal was to identify a brain signature for Muslims while

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87 Arabs were chosen for this study to avoid introducing a language factor into the study since Quran verses must be recited in Arabic during Salah.
praying. This initial study uncovered that Muslim prayer had a statistically significant effect on the practitioner brain. An increase in lower frequencies brainwaves (delta, theta and alpha) was witnessed during Salah.

The second EEG study evaluated the impact of using the eRug on the brain signature as compared to not using it. While using the eRug, participants maintained a generally similar brain signature to that recorded while praying without the eRug.

The goal of the longitudinal study was to evaluate the long term effect of the eRug on average practitioners. Study results showed that the eRug does indeed enhance the flow experience of those who used it.
Chapter 6

Conclusion

6.1 Summary

For more than a thousand years, the prayer rug has been used by Muslims, around the world, to conduct the five daily prayer rituals. The rug has undergone very little modification since it was first used – mainly esthetics in the form of adding non-distracting Islamic motifs and patterns. Innovations in flexible circuit technology have enabled the use of the rug itself as a sensing surface, opening the way for the development of an inexpensive mechanism for detecting user postures. This technology consists of flexible circuit and sonar for detecting user posture, an LCD with embedded microcontroller for displaying Quran pages, and a gesture interaction technique for communicating with the device.

This dissertation constitutes a significant contribution to the development of the first major enhancement to the prayer rug: an electronic version that neither compromises the traditional form nor the simple interaction associated with the passive device. In addition to preserving the form, the electronic version supports the display of Quran verses during Salah – enabling more than 1.5 Bn Muslims, for the first time, to read un-memorized parts of the Quran without disrupting their prayer routine or memorizing the Quran separately.

In Chapter 1, the main research questions that guided this dissertation were specified, namely; what obstacles face a Muslim while trying to fulfill the daily prayer obligations?
how can we help Muslims in enhancing their prayer quality? And what is the effect of using a digital system during prayer on user performance?

In Chapter 2, the results of a set of interviews with practicing Muslims and a scholar were presented and examined. A set of requirements was extracted from the interviews. These requirements guided the design effort in the four iterations of the eRug and included: notifying the user of prayer time and religious events, tracking performance of prayer, enabling access to religious scripture during prayer, using interaction techniques that will not add to the ritual, assisting in correcting errors, providing full control to the user, providing customization to the prayer experience, supporting pre-prayer and post-prayer supplication, and supporting Mecca-direction finding.

In Chapter 3 of this thesis, I surveyed the space of religious rituals and supporting tools. Given that designing for religious ritual is a very new and relatively unexplored area within HCI, developing the taxonomies presented in that chapter were crucial to the understanding of the possibilities and limitations associated with an electronic prayer rug.

In Chapter 4, a detailed chronological account of the development of the eRug versions was presented. Designing for a religious ritual turned to be more challenging than designing for secular tasks because religious rulings must be taken into consideration and these have their own logic of how and why a ritual should be conducted. Typical HCI evaluation criteria, such as efficiency, are not applicable in such a context. Several, not necessarily intuitive, design modifications such as not notifying the user of the specific error that was committed but only output an indication that an error has happened, had to be made to satisfy the religious requirements. Participants who volunteered in the early evaluations were crucial in uncovering functional and usability problems in the design.
Four versions were developed, in an iterative design process, before being able to conclude that the prototype was usable and satisfied the religious requirements. Out of the nine requirements, reported in Chapter 3, the latest version of the eRug supports the following five requirements; enabling access to religious scripture during prayer, using an interaction techniques that will not add to the ritual, assisting in correcting errors, providing full control to the user, and providing and customization to the prayer experience. The remaining four requirements; supporting pre-prayer and post-prayer supplication, supporting direction finding, tracking performance of prayer, and notifying the user of prayer times and religious events will be supported in future versions.

In Chapter 5, a set of objective and subjective evaluations were reported. Two EEG experiments were conducted to study the effect of the eRug on the users’ brain states during prayer. In the frontal and parietal lobes, the trend of low frequencies and higher coherence becoming dominant during Salah without the eRug, was further magnified by using the eRug. Hence, making users even more relaxed. In the occipital and temporal lobe, the eRug changed the brain performance from Salah without the eRug, due to the difference between praying on the eRug and praying without. While praying on the eRug, the participants read the Quran from an LCD which led to an increase in activity in the occipital lobe, and they did not recall Quran from memory. Overall, the impact of the eRug was positive since no increase in the beta and gamma waves were witnessed and the frontal lobe had lower frequencies dominant.

A final step in this thesis was to carry out a 4-month long longitudinal study to begin to evaluate the impact of the eRug on the flow experience. Overall, the user’s flow experience was enhanced at the end of the study providing initial evidence that the eRug

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88 Beta and gamma are associated with mental stress.
may indeed help users in the long term, by making them more engaged in the Salah and consequently more relaxed. As discussed in the motivation section\textsuperscript{89}, such an enhancement in prayer quality affects the overall life quality of the individual and not just the ritual experience.

The reported studies suffer from a number of limitations, namely; small number of participants and gender, language, ethnicity, and age biases. Those limitations arose from the inability to recruit a larger number of participants due to the small Muslim population in Toronto. Hence, results should be interpreted with caution.

6.2 Contributions

This dissertation’s contributions are a reflection of three inter-dependent directions; supporting Islamic prayer rituals through a digital interface, investigating appropriate means to evaluate digital devices used in religious rituals, and documenting and classifying the space of religious rituals and tools. Due to multifaceted nature of the thesis, the contributions are not limited to HCI but extend to neuro-theology, neuropsychology, psychology of religion, and anthropology.

This research commenced with an investigation challenges facing Muslims in fulfilling daily prayer. The interviews with practicing Muslims revealed that they are indeed facing challenges, and that they have developed several creative techniques to solve those challenges. A set of requirements drawn from the interviews with practicing Muslims and with a religious scholar were identified. This early study of Muslim prayer needs is the first of its kind. It is expected that followers of other religions would also adopt parallel

\textsuperscript{89} Section 1.1
techniques and strategies for the same purpose. Hence, this study should guide researchers designing for Muslim rituals and for other religions to conduct similar studies before designing an interface. From an anthropological standpoint, the study revealed that the traditional prayer rug has been weaved by the users into the environment in ways not reported before. This study also represents the first attempt to document the relationship between a tool for religious ritual and its users. Such tool-user relationship is a topic of interest to anthropologists.

The next step in the research was conducting a thorough review of various tools used in religious rituals, the design motivation, and constraints laid out by the religion. Modern digital tools were included in the review accompanied by a design critique. Two taxonomies were produced; one for tools and a second for rituals. Those two taxonomies should benefit HCI researchers delving into this new area. The goal was to help researchers to understand the different kinds of tools, rituals and the constraints associated with either – hence enable them to ask the right questions. Although the taxonomies were built with the HCI researcher in mind, the benefits extend beyond HCI. Classifications of rituals and tools, traditional or modern, have not been done before. Hence, it represents a much needed effort in attempting to understand and document religious rituals and associated tools. Researchers in the area of psychology of religion as well as anthropology should find such new addition to the literature beneficial and guiding.

The eRug was the final output of an iterative design process which experimented with different material, forms, and interactions techniques. The usage of flexible circuit layers has proven the most successful. It is the hope that this work will inspire other HCI
researchers to use this material in other interaction projects. The design of the electronic circuitry has been laid in detail to inform researchers desiring to build their own system. Several experiments were conducted to evaluate the eRug. EEG was explained in detail to provide future HCI researchers with enough information to be able to decide if it is the suitable tool for their evaluation. The conducted experiments showed that EEG could be used effectively in understanding and evaluating user status while performing a task. Even though the existing knowledge of how the human brain exactly works is still limited, the available measurement tools are accurate enough to capture changes between two or more conditions in an experiment. It is the hope that the EEG studies will be imitated by other researches to evaluate newly designed digital devices and interfaces.

While eastern religions have been studied extensively, Islamic rituals have not been studied using EEG. The EEG experiments are the first to inspect both EEG power and coherence of Muslims while praying. Thus, neuro-theologists should find the reported results a new proof that religious rituals do indeed affect the cognitive state of the user. One notable difference between the described EEG experiments and previous work in neuro-theology is using ordinary participants. All other neuro-theology experiments reported in the literature used expert participants. The fact that ordinary Muslims have showed such significant change during Salah is new. Neuro-theologists could use the reported results in comparing and contrasting the impact of different religions on the brain. Another contribution that is also new is the reported result that Muslims are experiencing a statistically significant delta increase during Salah – albeit a small one in magnitude. This finding should also be of interest to neuro-theologists.

Flow is a new concept that is being increasingly used in HCI to measure the engagement
of a user. Where neither objective measures nor physiological ones are available or feasible, flow is a third best alternative. A flow questionnaire, SFQ, to measure change in user performance, was designed, validated and used in a longitudinal study. This questionnaire could be utilized to measure the impact of a new device meant to be used with Salah.

6.3 Avenues for Future Research

6.3.1 eRug Future

Supporting Missing Features

The eRug would be modified to support the remaining four requirements uncovered from earlier interviews with practicing Muslims, namely; supporting pre-prayer and post-prayer supplication, supporting direction finding, tracking performance of prayer, and notifying the user of prayer times and religious events will be supported in future versions.

Evaluation on a More Heterogeneous User Base

Two limitations of the conducted evaluation studies are the low number of participants and the homogeneity of participants. Due to the time-line restrictions associated with this thesis and the relatively small Muslim population in Toronto, all the participants were Arab males, between the age of 20 and 50. In the future, a more diverse set of participants such as female Muslims, Senior Muslims, non-Arabic speaking Muslims, Muslims with disability, and Muslims who newly converted to Islam will be recruited.

Improving EEG Resolution

The EEG experiments were conducted using a 25 electrodes montage because this was
the available technology in the lab where the experiments were conducted. Utilizing a higher resolution, 64 or 128 electrodes, montage will enable the capture and analysis of a more accurate picture of the changes happening in the participant’s brain during Salah.

Improving Interaction Mechanisms

The participants’ feedback from the longitudinal study showed that the vibration represented a form of interference in Salah. One enhancement venue is to empirically evaluate different vibration levels and techniques to decide on the least intrusive vibration mechanism.

Another participant concern is the sensitivity of the sonar input. Several participants reported that the sonar was inaccurate in detecting their hand movement and they had to repeat the gesture several times before activating the interface or triggering selection in it. Using a sonar sensor as an input device is a new technique that might need refinement in the hardware, software and the gestures used.

Voice Recognition and Validation

Several participants in the longitudinal study requested adding a feature to enable the detection of pronunciation errors. Out of five daily required prayers, three prayers are performed with loud voice. Users sometimes mispronounce some of the words in the Quran due to the lack of training in pronunciation rules. Since it is religiously permissible to correct someone while praying in the case of mispronunciation, one possible enhancement is adding a voice recognition facility to the eRug to provide spontaneous correction to the users while they pray.

Biofeedback

Reminders of worldly affairs, often flash in the user mind during Salah. It is possible that
the brain waves will change from the low frequencies to higher frequencies once the user loses concentration in Salah and start thinking about worldly matters. If indeed this assumption is correct, then with the help of a portable EEG headset, the user can be notified that he is diverting away from prayer before the worldly thoughts take over and cause a complete loss of concentration. This concept of helping the user to maintain concentration is a new venue for HCI research and has application in the medical and educational field as well.

6.3.2 EEG-based HCI Evaluation

A second research direction is to develop a generic EEG-based HCI evaluation methodology – as an alternative to traditional objective HCI evaluation methodologies which typically consist of subjective analyses such as questionnaire, workload assessment and analyses of talk aloud data and relatively coarse grain biometric analyses such as GSR and heart rate variability. A generic EEG-based approach would have several advantages over traditional HCI measures: First, it is simpler to design an experiment. In traditional HCI methods, the evaluation is as good as the selected experimental design and statistical analysis. An EEG-based approach would tap into more fundamental phenomena – the brain signals – and it could be applied to any kind of interface with less reliance on the experimenter skills. Although conducting EEG experiments requires considerable skill, yet a trained technician can do it more effectively and efficiently without requiring prior knowledge in HCI. The second advantage of this approach is that it can more objectively reveal data of work load the brain experiences during various tasks and that might open a new way designing and evaluating user
interfaces. Using traditional evaluation techniques, one interface is better than another if the user can perform the task faster and with fewer errors. However, often these interfaces are used and evaluated over short periods of time and results can be affected by novelty (if an application is used for extended periods of time, it is important to confirm that the faster interface is not exerting more cognitive workload on the user’s brain. Otherwise, the faster interface may cause the user to perform more errors with extended usage.

6.4 Conclusion

It is my hope that HCI researchers will be aided by the findings and techniques presented in this thesis. It is my even greater hope that the techniques and approaches described in this thesis will inspire the next round of research into this important area of human-computer interaction, interfaces supporting religious practice.
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Appendix A: Salah Narrative Interview Questions

Translated from Arabic

1) I want to ask you to tell me how do you engage in performing the daily prayer rituals. The best way to do this would be for you to start from the early morning, and then tell all the things that are related to prayer, one after the other until the day is concluded. You can take your time in doing this, and also give details, because for me everything is of interest that is important for you.

2) I want to ask you if you are satisfied with the quality of your Salah? if yes, why? and if no, why?

3) I want to ask you if you whether your performance of Salah has changed over the years. How do you see your Salah 20 or 30 years ago versus your Salah in recent times?

4) Are there any challenges that face you related to the performance of Salah you would like to mention?
Appendix B: eRug Fatwa

Please, see section 4.2.3 Iteration 2: eRug – Peripheral Device: Religious Opinion of Iteration 2 for summary of the fatwa.
جبر وجماد رقادة. وقال ابن حزم: لا تخزى القراءة من المصحف ولا من غيره نص إمامًا كان أو غيره، فإن تعد ذلك بطلت صلاة، وبه قال ابن السبب والحسن والشعبي وأبو عبد الرحمن السلمي.

وقال الشيخ ابن باز: يجوز ذلك إذا دعت إليه الحاجة كما تخزى القراءة من المصحف في الورافع لن تخط القرآن، وقد كان ذكره مؤلوفة عاشية رضي الله عنها يصلي بها في رمضان من مصحف ذكره البخاري في صحيحه عليه تعلقاً به، وتطويل القراءة في صلاة الفجر، فإنما كان الإمام لا يخط المصحف ولا يخط من نسخ القرآن الكرم جاز له أن يقرأ من المصحف، ويشرع له أن يخط نسخ القرآن، وأن يجهد في ذلك، أو يخط المصحف على الأقل حتى لا يكون إلى القراءة من المصحف، وأول المفصل سورة في إلى آخر القرآن، ومن الهجاء في الحفظ يسر الله أمره، قوله سبحانه: (وَنُزِّلَ لَهُ مَخْرَجًا) وقوله عز وجل: (وَلَقَدْ نَسِئْنَا عَلَيْهِ نَبِيٌّ مُّكَرِّرًا فَغَلَّ فَيْهُ مَعَذَّرَاتِهِنَّ رَمَيَّةً) (رواه دلالة ابن ر חדש 117).

وقال الشيخ ابن عيينة رحمه الله: لا حرج في هذا أعني لا حرج أن يقرأ القرآن في الفريضة أو النهقاء من المصحف وهو يصل إلى ذلك حاجة وهو وإن كان فهو يتحرك بقلب الروق وحول المصحف ووضعه على الأرض أو على كرسي حوله، لكن هذا عمل يسير لسلطة الصلاة، أي ما يقمع هذا في صلاة الفجر يوم الجمعة فإن المشرع في صلاة الفجر يوم الجمعة أن يقرأ في الكرعة الأولى ثم ترتيب السجدة وهي التي بين سورة القادسية والأحزاب في المركمة الثانية، خلف كل سورة في فجر يوم الجمعة، وفي كل سورة بين قضية بضعة مواضع في فجر يوم الجمعة لن يقرأ أن يقرأ في كل سورة للسجدة ويبعث عليه رضوان العلماء، فهناك القراء الطويلون وما لا يس Hire لكل إمام أن يستفيدما عن ظهر قلب فلا يأت أن يقرأ بالمصحف فيما نقله في هذه المسألة، وهي أن بعض الأئمة يقسم سورة السجدة في الكرعتين أن يقرأ السورة التي تشبه سورة الإلسان في الكرعة الثانية وهذا غير الحال لأنه حين يكون شطر السنة فإما أن يأتي بالسنة الكاملة إما أن يقرأ بالسورة الأخرى.

وقال الشيخ عبد الله عبد الرحمن الجبري: لا يجوز ذلك داعيًا لما فيه من الاعتقال داخل الصلاة كناسك المصحف.

وقال الأوراق والنظر إلى الأطراف فإن الشيخ محبوري بأن ينظر إلى موضوع سجوده، وأن يضع يده على صدره، ثم أجاب لا يجوز أن يكون إمامًا رضي الله عنه، إلا بعد أن يخط القرآن ما ليل عن ثلاثة أجزاء ليضمن من القراءة في صلاة النهقاء من طول المفصل. أما إذا كان ذلك نسبًا يتجاوز كما أو احتاج إلى قراءة سورة لا يخطبها لن يضمن من السامع فله أن يقرأها من المصحف كما في صلاة الورافع وصلاة الكسوف.
منذما نطق في حالات الفراق، فقالوا إنما هو من صفين من عصبة السلم. ومنهم من أجازه من الكراث، ومنهم من منعه من زنادقة، وقد ورد في تحرير هذه الأقوال، كما ورد في تحرير هذه الأقوال.

وقد أثبت لأنفس المسلمين أن الكراث من أackbarهم، وقد ورد في تحرير هذه الأقوال.

لا يجوز استخدام الشفرة الإلكترونية للقراءة في القرآن إلا في الأجل الصحيح في القراءة الأولى وأن يختار المعطى ذلك ولا يكلف الله نفسي إلا وساعده ودفقه.

في حالة أداء صلاة الفراق والمسلمين بعث الماء الدفء واللوم في الماء الدفء، لا يجوز استخدام الشفرة الإلكترونية للقراءة لأن من شروط الإمام في صلاة المشي.

في حالة أداء صلاة الفراق والمسلمين بعث الماء الدفء واللوم في الماء الدفء، لا يجوز استخدام الشفرة الإلكترونية للقراءة لأن من شروط الإمام في صلاة المشي.

في حالة أداء صلاة الفراق والمسلمين بعث الماء الدفء واللوم في الماء الدفء، لا يجوز استخدام الشفرة الإلكترونية للقراءة لأن من شروط الإمام في صلاة المشي.

في حالة أداء صلاة الفراق والمسلمين بعث الماء الدفء واللوم في الماء الدفء، لا يجوز استخدام الشفرة الإلكترونية للقراءة لأن من شروط الإمام في صلاة المشي.

في حالة أداء صلاة الفراق والمسلمين بعث الماء الدفء واللوم في الماء الدفء، لا يجوز استخدام الشفرة الإلكترونية للقراءة لأن من شروط الإمام في صلاة المشي.

بالنسبة إلى استخدام نذاعات خلابة لثياب الإمام إلى قيمتيين في الصلاة، فلا يجوز لأن الواجع أن يقوم المولدين بثياب الإمام. أما في الحالات الأخرى، فالقرآن الفردية أو الصلاة والتصليح المذكور في ذلك.

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Appendix C: eRug 1.0 Questionnaire

ID/Ref: ____________

Post Study Questionnaire - Electronic Prayer Rug

The purpose of this questionnaire is to collect your opinion of the prayer assisting device you have just used. It is designed to be anonymous although your responses to the questions could possibly identify you. The questionnaire will not be linked to your name.

1) What did you like most about the electronic prayer rug?

2) What did you dislike most about the electronic prayer rug?

3) Any general comments, suggestions or recommendations are most welcome!
Appendix D: eRug 2.0 Firmware

```c
#include "D:\phdsoftware\erugusb.h"
#include "usb_cdc.h"

//!' This device continuously reads the key switches and spits out the data as
//!' : k1 k2 k3 k4 p CR
//!' where K1 to K4 are HEX2 format key data
//!' and p is BIN1 presence data
//!' Motor On = :M
//!' Motor Off = :m

// Configure the IOs
#define PA_mask    0x3F
#define PB_mask    0xFF
#define PC_mask    0x07
#define PD_mask    0xFF
#define PE_mask    0x0F

#define MotorPWM(x)    output_bit(PIN_C7,x);
#define PresencePin    PIN_C6

enum {OFF=0, ON};

// gather the status of the keys in here
int8  Keys[4];
int16 Inches;
```
void ReadKeys() {
    int8 tmpd,tmpe;

    tmpe = input_e() & PE_mask;
    tmpd = input_d() & PD_mask;

    Keys[0] = (input_a() & PA_mask) + ((tmpe & 0xC) << 4) ;
    Keys[1] = input_b() & PB_mask;
    Keys[2] = (input_c() & PC_mask) + (tmpd << 3);
    Keys[3] = (tmpd >> 3) + ((tmpe & 3) << 5);
}

// return a count proportional to the pulsewidth
int16 Get_Sonar() {
    int16 Timeout,Inches;
    int1 laststate=1;

    #use standard_io(c)
    Inches = 0;
    output_low(PresencePin);
    delay_us(10);
    output_high(PresencePin);
    delay_us(50);

    for (Timeout = 0; Timeout < 0xffff; Timeout++) {
        if (input(PresencePin) == 0)
void main() {
    setup_adc_ports(NO_ANALOGS|VSS_VDD);
    setup_adc(ADC_OFF);
    setup_psp(PSP_DISABLED);
    setup_spi(SPI_SS_DISABLED);
    setup_wdt(WDT_OFF);
    setup_timer_0(RTCC_INTERNAL);
    setup_timer_1(T1_DISABLED);
    setup_timer_2(T2_DISABLED,0,1);
    setup_comparator(NC_NC_NC_NC);
    setup_vref(FALSE);

    // set the pin directions here
    set_tris_a(PA_mask);
    set_tris_b(PB_mask);
    set_tris_c(PC_mask);
    set_tris_d(PD_mask);
    set_tris_e(PE_mask);
    MotorPWM(OFF);

    //Setup_Oscillator parameter not selected from Intr
    Oscillotar Config tab

    usb_init_cs();

    //output_low(PresencePin);
    while (TRUE) {
        usb_task();
        if (usb_cdc_kbhit()) {
            if (':' == usb_cdc_getc()) {
                //
            }
        }
    }
}
switch (usb_cdc_getc()) {
    case 'P':
        printf(usb_cdc_putc,":%02X%02X%02X%02X%05Lu\r",
            Keys[0], Keys[1], Keys[2], Keys[3], Inches);
        break;
    case 'M':
        MotorPWM(ON); break;
    case 'm':
        MotorPWM(OFF); break;
    case 'I':
    default:
        printf(usb_cdc_putc,"eRug\r\n"
            "Wael A.S.\r\n\n\n");
        break;
}
}

ReadKeys();
Inches = Get_Sonar();
Appendix E: eRug 3.0 Design Notes

Building an independent computer device involves five steps: 1) identifying the required performance and functionalities, 2) selecting the microcontroller, 3) selecting the peripheral components – such as external memory – that would work with the selected microprocessor, 4) determining the connectivity between the microcontroller and the selected components by referring to their respective data sheets, and finally 5) designing a PCB to house all the components.

The required performance from the eRug is quite moderate since the tasks of sampling the buttons, reading the sonar, controlling the vibrating disc motor and displaying Quran pages on the screen are not computationally expensive. Since the user spends significant time reading the displayed Quran pages, the screen refreshing requirement is also moderate.

An important decision in building an independent computer device is the selection of the microcontroller. After careful review of available microcontrollers, the Atmel AT91SAM9RL64 was selected because it supports a wide range of peripherals and has good speed. To store the Quran pages on the device, an SD card was used since the AT91SAM9RL64 microcontroller supports the SD interface. PADS Suite (2010) was used to verify the connectivity between the microcontroller and selected components. Next, a six layer PCB was built to house the components which were placed on the top layer and on the bottom layer of the PCB while the other four layers were used to route the buses between component pins.

This microcontroller is based on the ARM926 architecture (Figure A.1), runs at 190MHz and includes an integrated graphics LCD controller that supports screen resolutions up to
1280x860 with 16M colors, integrated USB device, in addition to the following peripheral interfaces: SDIO/SD/MMC, AC97, USARTs, SPIs, I2S and I2C.

The Atmel AT91SAM9RL64 also supports an external bus interface incorporating controllers for SDRAM, with specific interface circuitry for CompactFlash and NAND flash. Since users only need to read text of the screen, a low resolution 15” inch LCD was used. The LCD was a thin-film transistor monitor with two edge backlight units and 6-bit RGB pins interface. The LCD required special interfacing that was not directly supported by the selected microcontroller; hence it was driven by a Himax HX8834-A chip from the electrical LCD interface of the AT91SAM9RL64 microprocessor.

The HX8834-A is a high performance single-chip video processing chip. Most importantly, HX8834-A, with programmable timing control circuitry, can provide the suitable control timing to drive almost any LCD panel. Figure A.2 shows the connections required between the AT91SAM9RL64 microprocessor and the HX8834-A video processing chip.

For connecting the microprocessor to the external memory, the digital logic, schematic
Figure A.2: Microprocessor to LCD controller interface

and input/output port connections were adapted from the Atmel Corporation data sheet for the AT91SAM9RL64 Micro-controller.

Figure A.3a shows the Gerber of the six layers combined – the light gray lines are traces, yellow dots are vias\(^{90}\), copper in white, and pads\(^{91}\) are in green. Two hundred and thirty-seven Via connectors were used to connect the different layers and 1824 pads were used for placing components. The large number of pads was due to the need to connect to the interface pins of the microprocessor, the memory and other chips used in the PCB. Many PCB layout techniques have been taken into consideration while designing the PCB layout. Standard PCB layout procedures such as grounding unused general purpose I/O pins and routing wires at 45 degree turns to reduce interference was also implemented. Analog components were placed far apart from all the digital components as well as the

\(^{90}\) Holes to route electrical connection between any two layers.
\(^{91}\) Connection point between copper and component pin.
higher current components. Effective grounding techniques were used as most interference problems can be resolved using efficient grounding methods. The most effective way of reducing total power and ground inductance was to run the signal and
the return paths very close together. The power and ground traces were run with approximately identical geometry on opposite sides of the board. IC decoupling capacitors have also been used to remove the unwanted glitches which occur due to fast switching logic gates. These decoupling capacitors have been placed very close to all the IC’s so that they can provide instantaneous charge. Bulk capacitors have also been used so as to recharge these decoupling capacitors. CMOS inputs/outputs have very high impedance and consequently can float to any voltage if unconnected (Williams, 2005), and this voltage could be within a threshold switchover region of the gate. To prevent this, all the unused general purpose inputs/outputs micro-controller pins have been grounded via a 10 KΩ resistor.

Regarding trace widths and signal routing PADS Suite (2010) was used to find appropriate trace widths for the layout. The calculated trace width for the power and ground signals was approximately 44 mils, but was ceiled up to 50 mils. For all other signals, a width of 12 mils was used. Figure A.3b shows the bottom layer populated with components. All components were surface mount devices to reduce space and mass.

System Software

Running an operating system on bare bone hardware, i.e. a PCB with a microprocessor that has no software installed involves three levels; 1) hardware boot strapping, 2) software boot strapping, and 3) operating system loading. In the first step, the hardware automatically checks if suitable software is available and if one is found, the software is copied to the memory inside the microprocessor and given control over the hardware. It is this second loaded software that will load the operating system.

The AT91SAM9RL64 embeds a boot ROM code which provides a set of algorithms to
manage the hardware initialization (GPIO, CLOCK, SDRAM and so forth). The ROM code is enabled depending on Boot-Mode-Select pin. This ROM code scans the contents of different media like SPI Flash, NAND Flash and SDCard to determine if a valid application is available then it downloads the application into the internal memory and runs it. To implement the second level boot strapping, U-Boot (2008) is used.

UBoot is accountable for configuring the main interfaces and launching the operating system of choice. The Linux operating system, version 2.6.24 (Linux, 2010) is selected to run on this hardware since a cross-compiled version for the Atmel microprocessors family is readily available. The Linux operating system has prebuilt support for the hardware components used on the PCB and it loads appropriate drivers for devices, memory management units, and microprocessor architecture management libraries. Once the operating system is loaded, it acts as an abstraction between the hardware stack and software stack. Figure A.4 shows the software architecture on the board including the Linux operating system specifics.

![Figure A.4: eRug 3.0 controller and peripheral circuit boards.](image)
Appendix F: Muslim Religiosity Personality Measurement

Inventory

Section A: Islamic worldview

1. Certain rules ordained by Allah S.W.T. can be violated to achieve success in worldly life.
2. To fully develop their nations, Muslims cannot completely follow Islamic teachings
3. All Islamic laws can be modified to fulfill contemporary needs
4. People who impart beneficial knowledge to others will be rewarded for it in this world only
5. Islamic teachings do not fulfill the needs of human beings' natural state (fitrah). (negative item)
6. Islamic values are applicable only in certain situations, places and times (negative item)
7. Allah S.W.T. will not test a person who internalizes and practices religion. (negative item)
8. Damage and destruction that occur in the world are the negative results of non-believers' actions (negative item)
8. A man should leave his job when told by the doctor that he will die within a short time (negative item)
9. In emergency situations, Islam allows Muslims to abandon obligatory prayer (solat). (negative item)
8. Rasulullah created laws that were not given to him by Allah S.W.T. (negative item)
9. All laws/rulings in the Qur'an are for the advantage and well-being of Muslims only (negative item)
10. Rasulullah's teachings are for the advantage and well-being of Muslims only. (negative item)
11. Allah S.W.T. will not forgive people who commit sins intentionally (negative item)
12. All human activities must be done for the sake of Allah S.W.T.
13. Allah S.W.T.'s rules fulfill all of His creatures' needs.
14. All deeds (shari'ah) performed by Rasulullah were guided by revelation.
15. If Allah S.W.T. wills to destroy a place, both Muslims and non-Muslims living there may be affected.
16. Allah S.W.T. is knowledgeable of the movements of the sand particles at the bottom of the ocean.
17. Rainfall is controlled by angels that have been commanded by Allah S.W.T.
18. All deeds performed by people who have reached the age of puberty will be accounted for in the Hereafter.
19. Worldly life cannot be separated from life hereafter
20. People are far from Allah S.W.T. when they commit sins (negative item)

Section B: Religious Personality

21. I get enthusiastic about doing good deeds when people praise me (negative item).
22. I am willing to help old people when they need it.
23. I make effort to deepen my understanding of Islamic law.
24. I feel at peace when I hear the Qur'an recited.
25. I love my brothers and sisters in Islam as I love myself.
26. I use the lessons from the Qur'an and Hadith in my conversations.
27. I incline toward taking a side when my friends quarrel (negative item).
28. I try to understand the meaning of Qur'anic words/verses.
29. I establish good relations with my neighbors.
30. I find ways to recycle anything that can still be of use.

31. I feel sad when Ramadhan ends.

32. I invite others to perform obligatory prayer (solat).

33. I avoid something if I am unsure about its legal status.

34. I make effort to remember death often.

35. I do not pay alms (zakat) (negative item).

36. I find time to recite the Qur'an even if I am busy.

37. I immediately apologize if I wrong someone.

38. I thank Allah S.W.T when beggars come to my house.

39. I make effort to always follow the Islamic code of dress.

40. If I borrow money from someone, I will make a contract with them.

41. I create commotion in public (negative item).

42. I do all jobs assigned to me to the best of my ability.

43. I am the first to give salam when meeting another Muslim.

44. I will ridicule someone in return when they ridicule me, even during Ramadhan (negative item).

45. I continue to perform good deeds even if others might ridicule me for it.

46. I am particular about doing good deeds consistently even though they may be small.

47. I easily forgive my siblings when they hurt me.

48. I always obtain the facts before passing judgment.

49. I tend to rely on others when faced with difficulty (negative item).

50. I like to help the needy.

51. I do not expose the shortcomings of others.

52. I make effort not to display my personal good deeds.

53. I like to help my relatives.

54. I frequently discuss religious issues with my friends.
55. I make sure all my family members are following the teachings (sunnah) of Rasulullah.

56. I seek sympathy from others when I experience misfortune (negative item).

57. I avoid offending in any way when joking around with others.

58. I make an ongoing effort to increase the frequency of my non-obligatory (nafil) prayers.

59. I would give true information in court against someone even if he/she is my relative.

60. I would remove an obstacle that I see on the road, even if it is small.

61. I worry if I cannot pay debt on time.

62. I am involved in da'wah work.

63. I care about my good relations with my siblings.

64. I admonish my friends when they do wrong.

65. I perform my work duties enthusiastically because it is a form of worship (ibadat).

66. I fulfill all my promises.

67. I am not sensitive to the teachings (sunnah) of Rasulullah in my daily activities (negative item).

68. I make effort to obey Allah S.W.T.’s rules in every situation.

69. I assume that people talk about me because they are concerned about my well-being.

70. I always thank a person when they do something nice for me.

71. I assume that nobody is perfect.

72. I get jealous when my colleague/friend is more successful than me (negative item).

73. I make effort to have ablution (wudhu’) at all times.

74. I try to smile as much as possible.

75. I do not get angry when I am being scolded.
76. I tend to remain silent when someone degrades Islam in front of me.
77. I speak politely to my parents.
78. I do non-obligatory prayers (solat sunnat) wherever I am.
79. I forgive others who wrong me before they ask for my forgiveness.
80. I expect others to finish my work for me (negative item).
81. I get upset when I hear about the suffering of Muslims in other parts of the world.
82. I will keep a person's identity hidden when I talk about them and they are not present.
83. I like to join in when I hear people gossiping (negative item).
84. I do not neglect my friends' dignity.
85. I refer to the people who know when I feel uncertain about Islamic rulings.
86. I like to help the poor without anyone knowing.
87. I make effort to internalize the Prophet's ethical conduct in my daily life.
88. I throw rubbish in the trash bin when I see it lying around.
89. I feel worried when I hurt my parents.
90. I do not feel worried when I send negative e-mails/SMS messages/information to people (negative item).
91. I use public buses, walkways, etc. with care/respect.
92. I cannot tolerate people who disagree with me (negative item).
93. I am careful to follow Islamic social norms during all activities I am involved in.
94. I participate in recreational activities without neglecting religious norms.
95. I perceive all non-Muslims that I see as potential Muslims.
96. I respect all opinions.
97. I feel happy when someone says something good about one of my friends.
98. I am very conscious about my health.
99. I openly display my anger if somebody meddles with my belongings (negative item).
100. I tend to let setbacks in life distract me from my responsibilities and religious practice (negative item).

101. I am very comfortable admitting my mistakes.

102. I make a serious effort to fulfill wedding invitations.

103. I have started saving money for hajj since my early days.

104. I prefer to do any form of labor than to beg.

105. I gossip about others (negative item).

106. I make sure that when I read the Qur'an, I understand its demands.

107. I use other peoples' belongings without their permission (negative item).

108. I speak rudely to my parents when I am angry at them.

109. My siblings and I compete in serving our parents.

110. I enjoy working in a team.

111. I pay more attention to my friends than my parents (negative item).

112. I offer my guests the best of what I have when I am hosting them in my home.

113. I like to take advantage of opportunities to understand Islam with my family.

114. I look for opportunities to give charity.

115. I share my opinion when I think that it will improve a situation.

116. I do not enter a person's house until I am invited.

117. I follow the advice of my parents even though it may not be what I want.

118. I make effort to make my guests feel as comfortable as possible.

119. I set aside money every year for charity.

120. I work hard to achieve my goals in the specified time.

121. I pray the 5 compulsory (fard) prayers (solat) everyday.
Appendix G: Advertisement for Recruiting Participants

Translated from Arabic

Research Participants Needed

May peace be upon you,

I am a PhD student in the University of Toronto. I am conducting a study about Salah as part of my research and need Muslim male participants.

➢ Your identity will not be revealed.

➢ Study lasts for 1.5 hours and you may withdraw at anytime during study.

➢ A time and date convenient for you will be accommodated.

May God reward you.

An opportunity to participate in research about Salah.
Appendix H: Consent Form

Project Title: Evaluation of Prayer-assisting Device

Principal Investigators: Wael Aboulsaadat, University of Toronto wael@cs.toronto.edu (416)-731-4438
Deborah Fels, P.Eng., Ph.D., Ryerson dfels@ryerson.ca (416)-979-5000 ext. 7619

Consent to Participate in Study from Subject Information Form

The aim of this research is to investigate the effect of using a digital prayer rug on the performance of users while praying. In order to do this, we will ask you to mount EEG electrodes on head using 10-20 electrode placement system montage. Baseline EEG reading is obtained while still. Next, you will be asked to perform a prayer while the EEG cap is still mounted. You are also asked to complete two additional surveys, one prior to the study and one at the conclusion of the study.

Confidentiality
All raw data will be kept strictly confidential; however a summary of the data will be published in academic venues but no individual details will be identified in this summary. The information gathered from surveys will be strictly used for research and academic purposes with only the principal investigator and his supervisor having access to it.

Risks and Discomforts
A special paste will be used to enhance the conductance of EEG electrodes. This paste is a washable and non-drying. The paste ingredients are polyoxethylene 20 cetyl ether, water, glycerin, calcium carbonate, 1/2 propanediol, potassium chloride, gelwhite, sodium chloride, polyoxyethylene 20 sorbitol, methylparaben and propylparaben. Since the paste should not be used on participants with a history of skin allergies or sensitivity to cosmetics and lotions, if you have developed any form of skin allergy due to the use of chemicals, you are advised to withdraw from the study.

Other risks associated with participating in this study are minimal. You may experience some fatigue with the heat generated by tight contact of the EEG. However, you are able
to take breaks at any time or even stop participation in the study without penalty. You may also experience some discomfort with being filmed or audio recorded. In this case, you may choose not to participate in the study or record your opinions in writing and remain off camera.

**Expected Benefits**

Individual participants will not receive any direct benefits; however, this study will benefit the general community of practicing Muslims. We hope that this information may lead to improvements in the performance of Muslim prayer.

**Voluntary Nature of Participation:**

Participation in this study is entirely voluntary. If you do not wish to participate in this study it will not affect current or future relations with University of Toronto. If you choose to participate, you have the ability to leave the study at any time and for any reason without penalty. In addition, you may refuse to answer any questions or participate in any task at any point of the study without penalty.

**Questions about the Study:**

If you have any questions or concerns, about this study please feel free to contact Prof. Deborah Fels at 416.979.5000 ext. 7619. If you have any concerns or complaints about this study in regards to its ethical nature please contact the Office of Research Ethics, c/o Office of the Vice President, Research, Simcoe Hall, Room 109, 27 King's College Circle, University of Toronto, Toronto, ON M5S 1A1, Canada. Telephone: 416-978-4649. Fax: 416-971-2647.
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Consent Form to Participate in Study

I acknowledge that the research procedures described above have been explained to me and that any questions that I have asked have been answered to my satisfaction. I have been informed of that there may be a possible risk of psychological discomfort from being filmed or watching so many videos, however, strategies are in place to reduce this risk.

I have been informed of the alternatives to participation in this study, including my right not to participate and the right to withdraw without penalty. I hereby consent to participate in the study and to be video or audio recorded during the study. I have received a copy of the information sheet.

Signature of Participant: ______________________________

Name of Participant (please print): ______________________________

Date: ______________________________

The details of this study were explained to me by:

Name of Investigator: ______________________________

Date: ______________________________
Appendix I: Demographic Questionnaire

ID/Ref: __________

Demographic Questionnaire
The purpose of this questionnaire is to collect general information about you and your experience with prayer. The questionnaire is meant to be anonymous although your responses to the questions could possibly identify you. The questionnaire will not be linked to your name.

1) What is your age, please check one?

☐ 18-29
☐ 30-39
☐ 40-49
☐ 50-59
☐ 60-69
☐ 70+

2) What is your gender?  female  male

3) What is your first language? Please check one.

☐ English
☐ Arabic
☐ Other

4) Highest Education Completed (chose one only)

☐ Graduate Level
☐ Undergraduate Level
☐ High School
☐ Primary School

5) How many years of formal religious education (in College or University) have you studied?

☐ None
☐ 1~2 years
☐ 3~4 years
6) Select Your Proficiency in READING Arabic (choose only one)

☐ I do not read Arabic
☐ Limited knowledge
☐ Elementary knowledge
☐ General professional proficiency
☐ Advanced professional proficiency
☐ Equivalent to native proficiency
☐ Native proficiency

7) Select Your Proficiency in SPEAKING Arabic (choose only one)

☐ I do not speak Arabic
☐ Limited knowledge
☐ Elementary knowledge
☐ General professional proficiency
☐ Advanced professional proficiency
☐ Equivalent to native proficiency
☐ Native proficiency

8) Please, indicate if you have consumed any of the following listed drugs – or similar ones – in the last 12 hours:

☐ Antidepressants (e.g. Imipramine, Amitriptyline, Ipronazid…)
☐ Stimulants (e.g. Dextrostat, Adderal, Ritalin, Caffeine - e.g. Coffee or Tea, Nicotine…)

9) How many pages have you memorized from the Quran?

☐ 1~10 pages
☐ 11~20 pages
☐ 30~40 pages
☐ More than 40 pages

10) How do you keep track of the time-to-pray throughout the day? Please describe.
Appendix J: Salah Flow Questionnaire

Salah Concentration and Attenuation Questionnaire

For questions 1 – 13, please rate your level of agreement by circling the answer

1) During Salah, I often have to repeat a Sura or Tahyat because I feel I recited it mechanically.
   Strongly Agree Agree Neutral Disagree Strongly Disagree

2) After Salah, I am sometimes not sure about the actual number of steps I made.
   Strongly Disagree Disagree Neutral Agree Strongly Agree

3) After Salah, I sometimes feel guilty due to my performance.
   Strongly Agree Agree Neutral Disagree Strongly Disagree

4) I have to repeat a Salah after performing it because I feel it was not performed adequately.
   Strongly Agree Agree Neutral Disagree Strongly Disagree

5) I often make mistakes during Salah.
   Strongly Disagree Disagree Neutral Agree Strongly Agree

6) I feel agitated while attending a Jamaa Salah if the Imam recites a long sura (chapter).
   Strongly Disagree Disagree Neutral Agree Strongly Agree

ID/Ref: ___________
7) I feel exhausted attending a Jamaa Salah if the Imam recites a long sura (chapter).

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<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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8) I lose sense of time while performing Salah.

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<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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9) During Salah, interference (e.g. noise) would completely distract me and prevents me from concentrating in the practice.

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<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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10) During Salah, I feel lifted and spiritual.

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<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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11) I feel guilty if I do not perform Salah in the prescribed time.

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<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
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12) I am satisfied with my concentration level during Salah.

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<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
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13) I am satisfied with my attenuation level during Salah.

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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For questions 14 and 15, please place an x on the line scale

14) If minimal concentration is where you are thinking about things in your life at all times during prayer and maximum concentration is where you empty your mind of all that concerns and focused on prayer - rate your level of concentration during an average prayer. Place an x where you think your average concentration fits.

[1 2 3 4 5 6 7 8 9 10]

15) If minimal attenuation is where you are concentrating in performing the prayer but you feel your performance is routine and mechanical, you are just doing the moves and it lacks sincerity, while maximal attenuation is when your body, mind and soul are all focused in prayer with utmost sincerity and you feel every step and verse in prayer - rate your level of attenuation during an average prayer. Place an x where you think your average attenuation fits.

[1 2 3 4 5 6 7 8 9 10]
Appendix K: eRug 3.0 Questionnaire

ID/Ref: ___________

Post Study Questionnaire - Electronic Prayer Rug

The purpose of this questionnaire is to collect your opinion of the prayer assisting device you have used. It is designed to be anonymous although your responses to the questions could possibly identify you. The questionnaire will not be linked to your name. It will take about 15 minutes to complete.

1) Rate how difficult was it to learn to use the electronic prayer rug? Please circle one.

Very easy  Easy  Neither easy nor difficult  Difficult  Very difficult

2) How easy was it to use the electronic prayer rug during your prayer? Please circle one.

Very easy  Easy  Neither easy nor difficult  Difficult  Very difficult

Can you briefly explain why did you find it easy or difficult to use?

3) How helpful did you find the electronic prayer rug during your prayer. Please circle one.

Completely hindered me  Somewhat hindered me  Didn’t help or hinder me  Somewhat helped me  Helped me a lot

In what way did the electronic prayer rug help or hinder you?
4) Please rate how much the following elements interfered with your prayer

<table>
<thead>
<tr>
<th>Element</th>
<th>Did not interfere at all</th>
<th>Interfered a bit.</th>
<th>Interfered</th>
<th>Interfered greatly</th>
<th>Not applicable/did not notice</th>
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<tbody>
<tr>
<td>Vibration</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Display of the scripture pages</td>
<td></td>
<td></td>
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<tr>
<td>Material/noise of the rug</td>
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<tr>
<td>Color of the Rug</td>
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5) How appealing (in terms of appearance, color scheme, etc.) do you find the interface? Please circle one.

- Very appealing
- Appealing
- Neutral
- Unappealing
- Very unappealing

6) How difficult do you find the GUI navigation system is to use? Please circle one.

- Very easy
- Easy
- Neither easy nor difficult
- Difficult
- Very difficult

7) Rate your level of satisfaction with the amount of time it takes you to accomplish what you want with the eRug setup. Please indicate your response by circling the appropriate answer.

- Very Satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very Dissatisfied
8) Rate your level of satisfaction with the functionality provided by the eRug? Please circle one.

Very Satisfied  Satisfied  Neutral  Dissatisfied  Very Dissatisfied

9) Please rate how useful you found the electronic prayer rug in general? Please circle one.

Very useful  Useful  Didn’t matter  Not useful  Not useful

To me  at all

10) Would you recommend the electronic prayer rug to other Muslims? Check only one.

☐ I would not recommend it
☐ I would reluctantly recommend it
☐ I don’t care
☐ I would recommend it sometimes depending on the person
☐ I would highly recommend it.

11) What other functions/features would you like the eRug to have? Check all that apply.

☐ Larger Screen
☐ Interacting with eRug by touching the screen
☐ Colour-coded Quran text (to assist in pronouncing words correctly)
☐ Log and display of personal prayer performance
☐ Mecca locator/compass
☐ Other, please specify

12) Which one do you prefer: the electronic prayer rug or the traditional prayer rug and why?
13) What did you *like most* about the electronic prayer rug?

14) What did you *dislike most* about the electronic prayer rug?

15) Any general comments, suggestions or recommendations are most welcome!