

Behavioral and Metabolic Health in the Context of Ramadan Fasting

by

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Dedication

This dissertation is dedicated to my father, Ali Alwaleedi, and my mother, Hailah Alamari, for your endless love, sacrifices, encouragement, and prayers throughout my life.

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Pursuing the PhD degree has been the most challenging but fruitful experience that I have ever had in my life. I would not have been able to finish this dissertation and my PhD degree without the help and support from many incredible people.

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Abstract

Ramadan diurnal fasting (RDF) can alter behavioral and metabolic health, but these effects may vary by sociocultural context and exercise participation. This dissertation examined these effects through three aims. Aim 1 compared physical activity, sedentary behavior, sleep, anxiety, and mental well-being among 1,399 adults observing Ramadan in Saudi Arabia ($n = 1,115$) and the United States ($n = 284$). Aims 2 and 3 used a two-arm randomized controlled trial to assess the effects of moderate-intensity aerobic exercise combined with Ramadan fasting on body composition, resting energy expenditure, and cardiometabolic health in 27 metabolically healthy adults with overweight or obesity. Participants were randomized to Ramadan fasting alone (RDF; $n = 14$) or fasting plus exercise (RDF+EX; $n = 13$). The intervention included five 40-minute sessions weekly for four weeks at 65–75% of peak heart rate. Outcomes were analyzed using repeated-measures ANOVA with baseline fat mass as a covariate. Saudi participants reported more vigorous-intensity physical activity and walking and less sitting than U.S. participants. They also reported later sleep timing, poorer sleep quality, more anxiety, and lower mental well-being. The sociocultural context of Ramadan was thus associated with behavioral and psychological outcomes. For the exercise intervention, participants completed 70% of prescribed sessions, with high adherence to duration and intensity. Energy intake decreased similarly in both groups. Significant Group $\times$ Time interactions favored RDF+EX for visceral fat ($p = .018$, partial $\eta^2 = .210$), body weight ($p = .044$), and total fat mass ($p = .042$). Fat-free mass and resting metabolic rate were preserved in both groups. Cardiometabolic outcomes showed no significant interactions; systolic blood pressure decreased within RDF+EX

only. Glycated serum protein and monocyte chemoattractant protein-1 increased in both groups; insulin resistance rose non-significantly. Overall, Ramadan fasting was experienced differently across sociocultural settings. Combining moderate-intensity aerobic exercise was associated with reductions in body weight, fat mass, and visceral fat without compromising lean mass or resting energy expenditure, whereas glycemic and inflammatory markers did not differ between groups.

Chapter 1 Overview of the Dissertation

1.1 Background

Ramadan, the ninth month of the Islamic calendar, is of paramount religious significance to Muslims worldwide. It is commemorated as a sacred month that emphasizes community, prayer, reflection, and fasting. Ramadan occurs at a distinct time each year due to the lunar-based Islamic calendar, which means it is approximately 10 to 11 days earlier on the Gregorian calendar each year. One of the Five Pillars of Islam, which are fundamental practices that Muslims must adhere to, is the practice of Sawm, which involves fasting during Ramadan. Muslims abstain from eating, drinking, smoking, and engaging in illicit behavior from dawn until sunset during Ramadan. The fast is mandatory for all adult Muslims; however, certain groups are granted exemptions, such as small children, the elderly, those who are ill, pregnant or breastfeeding women, travelers, and individuals who are at risk of health complications during the fast. The primary objective of fasting during Ramadan is to foster self-discipline, spiritual development, and compassion for those who are less privileged.

The physiological and behavioral demands of fasting significantly alter the lifestyle behaviors of individuals who observe Ramadan fasting. During this period, critical components of daily life, including physical activity, sleep patterns, mental health, and psychological well-being, are influenced. Nevertheless, these modifications are contingent upon the cultural and societal contexts in which fasting is implemented, and they are subject to variation among distinct populations. In countries that are predominantly Muslim, such as Saudi Arabia, fasting is

frequently incorporated into the social and professional spheres, with structural modifications made to accommodate fasting individuals. For example, the timing of social events is often coordinated with the breaking of the fast, and there is significant societal support for the behavioral changes that are necessary during Ramadan. Additionally, business hours may be adjusted. These modifications can help fasting individuals maintain some physical activity, obtain adequate rest, and obtain social and psychological support

In contrast, Muslims practicing Ramadan in non-Muslim majority nations, such as the United States, may face unique challenges. Due to limited societal allowances for fasting, individuals have to balance their religious practices with regular work schedules and daily duties, which can lead to significant disturbances in sleep, physical activity, and mental health (Darzabi & Hejazi, 2020). The lack of wide social support may also have a negative impact on their psychological well-being during this time. These diverse cultural settings provide important insights into how contextual factors influence the fasting experience and associated lifestyle choices (Hassanein et al., 2024).

In addition to the behavioral aspects of Ramadan, fasting has been demonstrated to affect a diverse array of physiological and metabolic parameters, including body composition and cardiometabolic health. A variety of physiological adaptations, such as changes in body weight, fat mass, and other body composition parameters, can result from the prolonged periods of caloric restriction during fasting (Osman et al., 2020). Additionally, fasting has an impact on cardiovascular and metabolic health parameters, such as insulin sensitivity, lipid profiles, and blood pressure (Al-Jafar et al., 2021; Prasetya & Sapwarobol, 2021; Salim et al., 2013; Vardarli et al., 2014). For instance, Al-Jafar et al. (2021) observed reductions of 7.29 mmHg in systolic and 3.42 mmHg in diastolic blood pressure after Ramadan, findings that were supported by a

meta-analysis of 33 studies involving 3,213 participants. Findings regarding the effects of Ramadan fasting on insulin sensitivity have been inconsistent. Prasetya & Sapwarobol (2021) studied 27 healthy young men and reported improved insulin sensitivity, as indicated by significant reductions in serum insulin and HOMA-IR. In contrast, Vardarli et al. (2014) studied 19 healthy men and collected blood samples at sunset after approximately 15 hours of fasting. They observed a 20% reduction in insulin sensitivity accompanied by a compensatory 10% increase in β -cell function, as well as a 23% decrease in HDL-C and a 14% increase in LDL-C. The consequences of fasting are particularly noteworthy for individuals who are overweight or obese, as they may undergo greater metabolic changes (Ünalacak et al., 2011). Factors such as energy balance, meal timing, and physical activity levels during fasting periods can all influence these health outcomes (Bahammam, 2006; Bogdan et al., 2001).

Additional physiological adaptations can be induced by engaging in aerobic exercise while fasting, which can further improve metabolic health (Trabelsi et al., 2012). In a fasting state, aerobic training has been demonstrated to enhance insulin sensitivity, improve fat oxidation, and positively impact lipid metabolism (Vieira et al., 2016). The body adjusts its energy substrate preference, relying more on fat stores for fuel, because of fasting. This shift is further accentuated when aerobic exercise is incorporated, resulting in more substantial reductions in fat mass and enhancements in overall body composition (Maaloul et al., 2023). Furthermore, exercise during fasting has been linked to improved cardiovascular function, as evidenced by reduced blood pressure and improved endothelial function (Zainudin et al., 2022). Nevertheless, it is crucial to acknowledge that although aerobic exercise and fasting both individually promote metabolic health, their combined effects may differ due to individual's

baseline health status, the intensity and duration of the activity, and the nature of the activity (Haxhi et al., 2013).

The potential for improved metabolic and physiological outcomes is significant, particularly in individuals with overweight and obesity, when fasting and exercise are combined. Exercise enhances metabolic flexibility and promotes muscle preservation, whereas fasting creates a negative energy environment that promotes greater reliance on stored fat as a fuel source (Amanat et al., 2020). Kotarsky et al. (2021) suggest that this combination can improve the efficacy of weight management strategies by promoting fat loss while preserving lean body mass. Additionally, it has been demonstrated that fasting combined with exercise can improve lipid profiles, reduce systemic inflammation, and enhance insulin sensitivity in overweight and obese individuals more effectively than either fasting or exercise alone (Frampton et al., 2021). According to a study by Dai et al. (2024), the integration of aerobic exercise with fasting may result in more significant improvements in body composition, cardiovascular function, and glucose metabolism in healthy subjects with overweight and obesity. These improvements contribute to the reduction of chronic disease risk factors associated with obesity.

1.2 Statement of the Problem

Even though Ramadan fasting induces substantial behavioral and metabolic changes, there is a dearth of comprehensive research that investigates the full extent of its effects, particularly in populations with specific health concerns, such as obesity and overweight, and across various cultural contexts. Although Ramadan is observed worldwide, the cultural and environmental factors that surround it are likely to influence the variations in lifestyle behaviors, such as physical activity, sleep patterns, and mental health. However, it remains unclear how

these behaviors differ between Muslim-majority and non-Muslim-majority countries, such as Saudi Arabia and the United States.

Furthermore, while intermittent fasting has been associated with improved cardiometabolic health, the effects of Ramadan fasting, particularly when combined with structured aerobic exercise, remain unclear in individuals with obesity and overweight. Even though these populations are at an increased risk of metabolic disorders, there is a lack of understanding regarding the impact of fasting and exercise on critical outcomes during Ramadan, including body composition, glycemic control, and energy expenditure.

1.3 Significance of the Dissertation

This dissertation is highly relevant to public health and clinical research, as it addresses critical gaps in understanding the effects of Ramadan fasting on behavioral and metabolic health. It also offers insights into the cross-cultural disparities in lifestyle patterns among fasting individuals, notably comparing Muslim populations in the United States and Saudi Arabia. This dissertation enhances understanding of the Ramadan fasting experience across two distinct sociocultural contexts by examining physical activity, sleep, and mental health in Saudi Arabia, where daily schedules, social activities, workplace routines, and religious practices often change substantially during Ramadan, and in the United States, where fasting is typically observed within a society that largely maintains its usual work, school, and daily-life schedules.

Furthermore, this dissertation is particularly important due to its emphasis on individuals with overweight and obesity, a demographic at heightened risk for metabolic disorders, including type 2 diabetes and cardiovascular diseases. Examining effects of combined Ramadan fasting and structured exercise on body composition, energy expenditure, and cardiometabolic health

provides essential insights for formulating effective health interventions for individuals at elevated metabolic risk. This dissertation offers novel insights into the interaction of these variables during fasting, potentially informing health guidelines and recommendations for Muslims participating in physical activity during Ramadan.

1.4 Specific Aims

This dissertation aims to examine the effect of Ramadan fasting from three distinct perspectives: (1) a cross-cultural comparison of lifestyle behaviors, including mental health, sleep patterns and quality, and physical activity (2) the effects of fasting combined with aerobic exercise on body composition and energy expenditure, and (3) the impact of fasting and exercise on cardiometabolic health markers, including glycemic control markers, blood pressure, and lipids profile in individuals with overweight and obesity. Each aim addresses a different aspect of how Ramadan fasting interacts with lifestyle and metabolic health to help build a comprehensive understanding of the behavioral and metabolic effects of Ramadan fasting.

Aim 1: To examine and compare mental health, physical activity behaviors, and sleep quality and patterns during the month of Ramadan among fasting participants in the United States and Saudi Arabia.

Hypothesis 1A: Fasting participants in Saudi Arabia will report significantly lower levels of stress, anxiety, and depression compared to their US group counterparts.

Hypothesis 1B: Fasting participants in Saudi Arabia will report significantly fewer minutes of physical activity per week and more time spent in sedentary activity compared to their counterparts in the United States.

Hypothesis 1C: Fasting participants in Saudi Arabia will report significantly lower sleep quality and shorter total sleep time compared to their counterparts in the United States.

Aim 2: To investigate the effect of Ramadan fasting combined with five weekly 30-minute sessions of moderate-intensity aerobic exercise over four weeks on body composition and resting metabolic rate (RMR) in metabolically healthy adults with overweight and obesity.

Hypothesis 2A: Participants in the exercise group will demonstrate a significant reduction in body fat percentage and fat mass compared to the comparison group following the month of Ramadan.

Hypothesis 2B: There will be no significant difference in resting metabolic rate (RMR) between the exercise group and the comparison group following the month of Ramadan

Aim 3: To investigate the effect of Ramadan fasting combined with five weekly 30-minute sessions of moderate-intensity aerobic exercise over four weeks on lipids profile, glycemic control markers, and blood pressure in metabolically healthy adults with overweight and obesity.

Hypothesis 3A: Participants in the exercise group will demonstrate a significant improvement in total cholesterol (TC), low-density lipoprotein (LDL), high-density lipoprotein (HDL), and triglycerides (TGs) compared to the comparison group following the month of Ramadan.

Hypothesis 3B: Participants in the exercise group will demonstrate a significant improvement in fasting blood glucose (FBG), fasting insulin (FI), and insulin resistance (HOMA-IR) compared to the comparison group following the month of Ramadan.

Hypothesis 3C: The intervention group will demonstrate a significant improvement in systolic blood pressure (SBP) and diastolic blood pressure (DBP) compared to the comparison group following the month of Ramadan.

Chapter 2 Literature Review

Understanding the effects of Ramadan fasting on behavioral and metabolic health requires a thorough examination of the existing literature. This chapter reviews current knowledge on the key domains impacted by Ramadan fasting, focusing on behavioral health, body composition, energy expenditure, and cardiometabolic health. The discussion begins with an exploration of how Ramadan fasting influences lifestyle behaviors such as physical activity, sleep, and mental health, emphasizing cross-cultural variations and adaptations. Following this, the review delves into the physiological effects of Ramadan fasting on body composition and energy expenditure, highlighting changes in substrate utilization and weight regulation. Finally, it examines the cardiometabolic health implications of Ramadan fasting, including its effects on lipid profiles, blood pressure, and glycemic control. By synthesizing insights from prior research, this chapter provides a foundation for understanding the multifaceted health impacts of Ramadan fasting and identifies gaps that this dissertation seeks to address.

2.1 Mental and Behavioral Health During Ramadan

2.1.1 Physical Activity

Prior research has extensively examined the effects of Ramadan fasting on physical activity. Ramadan fasting, which involves abstaining from food and drink from dawn until sunset, significantly alters daily routines, including physical activity patterns, intensities, and durations. The existing studies have employed various measurement tools to assess physical activity, ranging from objective measures such as accelerometers (ActiGraph GT9X, Fitbit Flex

2, Sense Wear Pro Armband) and pedometers to subjective assessments through validated questionnaires like the International Physical Activity Questionnaire (IPAQ). Using both objective and subjective measures provides a broader understanding of physical activity patterns, although differences among measurement methods may limit comparisons across studies.

Studies using subjective assessment tools have reported mixed findings on changes in physical activity during Ramadan fasting. Several studies reported no significant changes in physical activity patterns during Ramadan. For instance, research conducted by Al-Hourani & Atoum (2007) in Jordan using an activity diary record found no significant changes in physical activity levels during fasting among 21 college female students. Similarly, Al-Barha & Aljaloud (2019) observed no significant differences in physical activity patterns and sedentary behavior among 44 male college students during Ramadan. Likewise, Abdallah et al. (2023) conducted an observational study in Italy involving 21 healthy adults who completed the International Physical Activity Questionnaire (IPAQ) at three time points, including before, during, and after Ramadan. Participants reported stable physical activity levels across all periods. However, Slimani et al., (2022) showed that PA level measured with the IPAQ was reduced in the last week of Ramadan in 57 secondary school teachers. Conversely, Parkash et al. (2023) revealed an increase in PA minutes during Ramadan compared to before Ramadan for the total sample and by gender.

However, several studies using objective measures reported reductions in physical activity during Ramadan. Alsubheen et al. (2017) conducted a study involving nine healthy males in a fasting group and eight healthy males in a non-fasting group. Physical activity levels were measured using a Vivofit activity tracker (Garmin International Inc.). The study revealed that the non-fasting group recorded higher daily step counts and covered greater total distances than the fasting group. Likewise, Lessan et al. (2018) reported lower physical activity levels

measured with ActiGraph GT9X during Ramadan compared to the post-fasting period among six males and five females. Similar findings were reported by Harder-Lauridsen et al. (2017). The study found that 10 healthy participants experienced a slight decrease in mean daily steps during Ramadan, as measured by a pedometer, but the Actiheart monitor showed no change in physical activity. (Farooq et al., 2021) objectively assessed habitual physical activity in 209 adults in Qatar and found that daily step counts decreased significantly among participants who fasted during Ramadan, whereas they increased among non-fasting participants. Physical activity among fasting participants remained below pre-Ramadan levels for several weeks afterward, highlighting the need for strategies to maintain activity during and after Ramadan

Furthermore, the effect of Ramadan fasting on physical activity seems to differ among various populations. In a study of 36 individuals with Type 2 Diabetes Mellitus (T2DM), physical activity levels, assessed using Fitbit and IPAQ, showed no significant differences during Ramadan compared to the post-Ramadan period. Notably, the study found a significant correlation between the Fitbit-recorded data and the self-reported physical activity outcomes from the IPAQ (Alghamdi et al., 2020). Another study of 75 individuals with Type 2 Diabetes Mellitus (T2DM) reported a significant decrease in physical activity levels, measured in METs per day, during Ramadan compared to the periods before and after fasting (Khan et al., 2012). Additionally, Alinezhad-Namaghi et al. (2019) observed significant decreases in total physical activity scores among 96 individuals with metabolic syndrome during Ramadan.

Several studies have reported that changes in physical activity during Ramadan vary according to activity intensity. Slimani et al. (2022) found a notable decline in high- and moderate-intensity physical activity during Ramadan compared to pre-fasting levels, while light-intensity walking activity remained consistent throughout the study periods. Another study by

Alghamdi et al. (2020) observed an increase in moderate-intensity physical activity levels following Ramadan compared to during the fasting period, as measured using FitBit devices. However, no significant changes were detected in vigorous-intensity physical activity or light-intensity walking across the study periods. Together, these findings suggest that moderate- and high-intensity physical activity may decline during Ramadan, whereas light-intensity activity tends to remain stable.

2.1.2 Sleep

Sleep is one of the most notably impacted behavioral patterns during the month of Ramadan. During Ramadan, food and water intake is limited to nighttime hours. The substantial amount of food consumed at night, along with heightened nocturnal social activities and prayers such as Tarawih, may influence the sleep-wake patterns of Muslims (BaHammam, 2003).

Research consistently demonstrates that Ramadan fasting leads to significant alterations in total sleep time (TST). BaHammam et al. (2013) conducted an observational study involving eight healthy Muslims and eight non-Muslims during Ramadan in Saudi Arabia. The study found that TST in the Muslim group generally decreased by 1–2 hours compared to the non-Muslim group, whose TST remained unchanged. Additionally, the timing of sleep in the Muslim group shifted to later hours, primarily due to the timing of the post-sunset (Iftar) and pre-dawn (Suhoor) meals. Similarly, a systematic review and meta-analysis of 24 studies found that participants consistently reported a one-hour reduction in TST during Ramadan (Faris et al., 2020).

Additionally, Sleep architecture undergoes notable changes during Ramadan. Sleep architecture refers to the structural organization of sleep, including the cycling and distribution of sleep stages throughout the night (Carskadon & Dement, 2005). Bahammam (2004) observed

significant reductions in rapid eye movement (REM) sleep duration and slow-wave sleep (SWS) in eight healthy males during Ramadan compared to before Ramadan. Their polysomnographic data also showed that sleep latency decreased by approximately 17 minutes. In contrast, A. S. Bahammam et al. (2013) conducted a crossover study with eight healthy males. Participants were asked to fast a month prior to Ramadan to evaluate the effects of intermittent fasting during and outside of Ramadan, thereby accounting for lifestyle changes. The study reported that the percentage of REM sleep was significantly lower during fasting outside of Ramadan ($17.7 \pm 8.1\%$) and during Ramadan ($18.6 \pm 10.7\%$) compared to baseline levels ($25.6 \pm 4.8\%$).

Mixed findings have been reported regarding sleep quality during Ramadan. A study by Boukhris et al. (2019) used Pittsburgh Sleep quality index (PSQI) and found that sleep quality score was higher during and after Ramadan as compared to before Ramadan in fourteen physically active males in Tunisia. Similarly, Elias et al. (2022) showed that overall sleep quality from the global PSQI score was significantly improved during Ramadan as compared to before Ramadan among 106 healthy young adults in Malaysia. However, a systematic review of six studies showed that individuals who continued to train during Ramadan experienced a reduction in sleep duration and impairment of sleep quality (Trabelsi et al., 2022).

Environmental and individual factors also play a crucial role in shaping the impact of Ramadan fasting on sleep quality. Several environmental variables that influence sleep quality during Ramadan, including ambient temperature, daylight duration, and cultural activities (Trabelsi et al., 2019). Individual characteristics such as age, gender, and chronotype also play crucial roles in determining the extent of sleep quality deterioration. BaHammam et al. (2010) reported that young healthy men and evening chronotypes experience more pronounced effects on sleep quality during Ramadan.

2.1.3 Positive Mental Health and Well-Being

The impact of Ramadan fasting on mental health, particularly concerning stress, depression, and anxiety, has become an increasingly significant area of research. The unique context of Ramadan, which combines fasting with spiritual activities, presents a complex interplay of psychological and physiological factors that can affect mental health. Heun (2018) conducted a comprehensive systematic review of 22 studies reported that Ramadan fasting is generally safe in healthy people; however, additional caution is warranted for those with schizophrenia or bipolar disorder.

Moreover, the psychological benefits of fasting during Ramadan may also be related to the increased sense of community and spirituality that accompanies this period (Alghafli et al., 2019). The communal aspects of Ramadan, such as shared meals and collective prayers, can foster social support, which is a crucial buffer against stress and anxiety. The sense of belonging and purpose of life derived from these communal activities can enhance overall mental well-being, providing a counterbalance to the potential stressors associated with fasting. Furthermore, Jandali et al. (2024) indicated that participants reported varying levels of depression during Ramadan, with many experiencing improved mood due to the spiritual and social dimensions of the observance.

The literature presents mixed findings. While some studies indicate that Ramadan fasting can lead to reductions in depressive symptoms, others highlight potential negative effects. For instance, Koushali et al. (2013) conducted a pre-and post-study of 313 female nurses in Iran and found that depression level was significantly reduced after Ramadan compared to before Ramadan. Similarly, Nugraha et al. (2017) reported that Ramadan fasting had a positive effect on depression among 50 young healthy subjects in Germany. However, Chennaoui et al. (2009)

found that eight middle-distance athletes documented no change of depression scores between days 0, 21, 31 of Ramadan. Chtourou et al. (2011) tracked 20 soccer players a week before and during Ramadan and reported no change in depression scores between the week before, week one, and week four of Ramadan.

The relationship between fasting and anxiety is also complex. A study of 242 medical students in Malaysia demonstrated that Ramadan fasting effectively reduced anxiety scores among both students with existing anxiety and those without (Ridho & Futihandayani, 2024). Similarly, Mousavi et al. (2014) found that there was a significant positive relationship between fasting and anxiety post-Ramadan in 110 Iranian subjects. Contrary to previously published studies, Nugraha et al. (2017) used the Hospital Anxiety and Depression Scale (HADS) to evaluate mental health parameters among 25 fasting and 25 non-fasting individuals. The study found that Ramadan fasting had no significant impact on anxiety levels compared to the non-fasting group.

Stress-related research generally indicates positive outcomes during Ramadan. Ahmad et al. (2017) investigated stress levels among 200 healthy adult Muslims using a self-reported scale and found that Ramadan fasting effectively reduced stress levels after Ramadan compared to before. Conversely, Alotaibi et al. (2023) carried out a prospective cohort study of 109 female and 111 male medical students. The study reported that perceived stress is higher among male students compared to their female counterparts even though students show healthier dietary and lifestyle behaviors during Ramadan. Although these studies relied on self-reported measures, stress responses during Ramadan can also be evaluated using physiological biomarkers such as cortisol. Cortisol, a hormone belonging to the glucocorticoid class, is produced in the adrenal cortex and is linked to stress-related disorders (Blair et al., 2017; Young, 2004). Numerous

studies have utilized cortisol as an indicator to assess the impact of Ramadan fasting on stress. Haouari et al. (2008) Investigated cortisol variations on three specific days during Ramadan: day one (as a control), day seven, and day twenty-one. The results revealed that nocturnal cortisol levels were elevated during Ramadan compared to the control period, with significant increases observed at midnight on both day seven and day twenty-one.

Lifestyle behaviors during Ramadan may play an important role in shaping mental health and overall well-being. For instance, Lauche et al. (2024) conducted a randomized controlled trial with 114 healthy adult Muslims. Participants were assigned either to a modified fasting group, which received educational materials on dietary and lifestyle modifications before Ramadan, or to a control group that observed Ramadan fasting as usual. The results indicated that pre-Ramadan dietary and lifestyle guidance may produce short-term improvements in the mental and physical well-being of adults observing Ramadan. Additionally, the psychological impact of fasting may vary based on individual health conditions. Yousuf et al. (2021) conducted an observational study involving 100 individuals with diabetes and reported post-Ramadan improvements of 23% in depression, 26% in anxiety, and 35% in stress levels.

The mental health effects of Ramadan fasting may also differ based on whether the individual is fasting in a majority-Muslim or non-majority-Muslim country. In majority Muslim countries, the communal and societal environment often aligns with fasting practices, fostering a supportive atmosphere that can reduce stress and anxiety while enhancing feelings of belonging and purpose. A study by Jandali et al. (2024) showed that the communal prayers and collective rituals of Ramadan can strengthen social bonds and alleviate symptoms of depression.

Conversely, Muslims fasting in non-majority-Muslim countries may face unique challenges, such as social isolation, work schedules that conflict with fasting hours, or limited

access to halal food options during iftar. These factors can exacerbate feelings of stress and anxiety. Research indicates that individuals in these environments might experience greater psychological strain, particularly if they face discrimination or a lack of understanding about Ramadan (Latif et al., 2025). However, the act of maintaining faith-based practices in a minority context can also foster resilience and a stronger sense of identity that provide mental health benefits that counterbalance the challenges.

2.2 Body Composition and Energy Expenditure During Ramadan

2.2.1 Ramadan Diurnal Fasting and Body Composition

Intermittent fasting (IF) refers to dietary patterns that alternate defined periods of eating and fasting without necessarily prescribing overall caloric restriction. Common forms include alternate-day fasting, the 5:2 approach, and time-restricted feeding, in which daily food intake is limited to a specific time window. Ramadan fasting represents a unique form of time-restricted feeding (TRF), where individuals abstain from food and drink from dawn to sunset for 29-30 days. Studies examining the effects of fasting during Ramadan on anthropometric parameters and body composition have shown mixed but generally favorable results. For instance, Al-Jafar et al. (2023) conducted a meta-analysis of 66 studies involving a total of 7,496 participants. The findings indicated that Ramadan fasting is associated with reduced body weight, BMI, and waist and hip circumference. These reductions typically begin during the second or third week of Ramadan, become statistically significant by the fourth week, reaches a peak immediately following Ramadan, and gradually diminish within 3 to 6 weeks post-Ramadan. A systematic review found that Ramadan fasting led to significant weight loss in both men and women. However, this weight loss was regained within a few weeks after Ramadan, highlighting the

influence of lifestyle changes associated with the fasting period on these outcomes (Sadeghirad et al., 2014).

Studies focusing specifically on overweight and obese populations have demonstrated more significant impacts on body composition. A recent systematic review and meta-analysis of 70 studies with 2947 participants showed a significant reduction in fat percentage post-Ramadan compared to before in individuals with overweight or obesity but not in those of normal weight (Fernando et al., 2019). Similarly, McNeil et al. (2014) observed significant reductions in body weight, waist circumference, fat mass, and fat-free mass during Ramadan compared to before and after Ramadan in a group of 10 obese males compared to 10 normal-weight males. An unpublished meta-analysis from our laboratory, including 23 pre-post studies and 780 participants with obesity, found modest reductions in body weight, BMI, waist circumference, and fat mass during Ramadan. These changes were generally small by the second week, became more pronounced by the fourth week, and partially diminished after Ramadan, suggesting that the effects were greatest near the end of the fasting month and were not fully maintained afterward.

Combining Ramadan fasting with a structured exercise regimen appears to enhance its effects on body composition. In a study by Trabelsi et al. (2013), 16 male bodybuilders were divided into two groups: one performed resistance training three days per week in a fasted state during the late afternoon (8 participants), while the other trained in an acutely fed state during the late evening (8 participants) throughout Ramadan. The results indicated that both groups remained unchanged in BMI, body fat percentage, and lean mass during the fasting period. Maaloul et al. (2023) conducted a study involving 20 individuals with obesity, who were randomized into either group: fasting only and fasting combined with concurrent exercise. The

exercise protocol consisted of endurance training (high-intensity interval training, HIIT) followed by resistance training, performed four days a week in the late evening during Ramadan. Both groups demonstrated significant improvements in body weight, fat mass, fat percentage, and waist circumference, with the exercise group showing greater improvements in these outcomes during Ramadan. Additionally, fat-free mass significantly decreased in the fasting-only group, while it remained unchanged in the exercise group.

Comparison with other forms of intermittent fasting reveals interesting parallels. Correia et al. (2021) conducted a systematic review and meta-analysis of 34 studies on Ramadan fasting and 32 studies on other forms of intermittent fasting (IF) to evaluate their effects on body composition parameters. The analysis revealed that non-Ramadan IF effectively reduces body weight, BMI, and absolute fat mass, while Ramadan fasting is associated with reductions in body weight and relative fat mass. The study concluded that Ramadan fasting induces beneficial adaptations for weight management; however, non-Ramadan IF demonstrates greater efficacy in improving overall body composition.

2.2.2 Ramadan Diurnal Fasting and Energy Expenditure

Intermittent fasting (IF) has emerged as a significant dietary intervention strategy, with various protocols ranging from alternate-day fasting to time-restricted feeding (Patterson et al., 2015). The effects of these fasting regimens on energy expenditure, particularly in individuals with overweight and obesity, have been widely studied, with growing interest in their combination with exercise interventions.

Studies examining the metabolic effects of intermittent fasting have demonstrated complex interactions between fasting duration, timing, and energy expenditure. Heilbronn et al.

(2005) showed that alternate day fasting led to modest reductions in respiratory quotient (RQ) after 22 days, which resulted in an average daily increase in fat oxidation. However, these changes were less pronounced than those typically observed during continuous caloric restriction (Varady et al., 2009). One possible explanation for this preservation of RMR is that intermittent energy restriction may attenuate the metabolic adaptations commonly observed with continuous energy restriction, although evidence for this mechanism remains mixed. Time-restricted eating (TRE), where daily food intake is confined to a specific window, has shown particularly promising results regarding energy expenditure. A study by Moro et al. (2016) demonstrated that an 8-hour feeding window, when combined with resistance training, helped maintain fat-free mass and resting energy expenditure in 34 trained individuals. However, these findings have limited applicability to the present study because the participants were trained individuals, the intervention involved resistance exercise, and the fasting protocol permitted fluid intake. These conditions differ substantially from Ramadan dry fasting combined with moderate-intensity aerobic exercise in adults with overweight or obesity.

Ramadan fasting presents a unique model for studying the effects of dawn-to-sunset fasting on energy expenditure. A relatively small body of literature assesses resting metabolic rates (RMR) during Ramadan using indirect calorimetry. Lessan et al. (2018) examined the effects of Ramadan fasting on RMR and total energy expenditure (TEE) in 29 healthy, non-obese individuals using indirect calorimetry during and after Ramadan. The findings revealed that RMR remained unchanged throughout the study period. However, RMR was significantly higher during the first week of Ramadan than subsequent weeks. Similarly, El Ati et al. (1995) conducted a study involving sixteen women, which showed a significant reduction in energy expenditure (EE) between 1100 and 1700 hours during Ramadan. In contrast, nighttime energy

expenditure remained unchanged throughout the fasting period. Consistent with these findings, a study involving nine healthy Muslims revealed no changes in energy expenditure or resting energy requirements (RER) on days 10, 20, and 30 of Ramadan compared to the post-Ramadan period (Alsubheen et al., 2017).

Although several studies have examined the effects of Ramadan fasting on energy expenditure, little is known about whether a feasible, structured moderate-intensity aerobic exercise prescription performed during Ramadan can preserve resting metabolic rate or alter substrate utilization in adults with overweight or obesity. Most previous research has examined Ramadan fasting alone or has evaluated exercise modalities and populations that differ substantially from those included in the present study.

2.3 Cardiometabolic Health During Ramadan

The impact of Ramadan fasting on lipid profiles has demonstrated variability across studies. Several investigations have reported favorable changes, particularly in high-density lipoprotein cholesterol (HDL-C) levels. For instance, Al-Rawi et al. (2020) and Faris et al. (2022) observed significant increases in HDL-C, along with concurrent reductions in low-density lipoprotein cholesterol (LDL-C). Similarly, Lubis and Pase (2020) reported a significant elevation in HDL-C levels among individuals with obesity, although the reduction in LDL-C levels in this group was slight and not statistically significant.

Studies have reported inconsistent effects of Ramadan fasting on lipid profiles.. Ganjali et al. (2016) observed an improvement in HDL-C levels by the end of Ramadan; however, this was accompanied by significant increases in both LDL-C and total cholesterol (TC). Similarly, Madkour et al. (2019) reported significant reductions in total cholesterol, triglycerides, and

HDL-C. Additionally, McNeil et al. (2014) documented a significant increase in total cholesterol and LDL-C levels during the fasting period.

The effects of Ramadan fasting on blood pressure parameters exhibit relatively consistent findings across studies. Hasan et al. (2022) reported significant reductions in both systolic and diastolic blood pressure, accompanied by improvements in total cholesterol and triglyceride levels. These results were supported by Ünalacak et al. (2011), who similarly observed significant decreases in systolic and diastolic blood pressure compared to pre-Ramadan values. Additionally, Ismail et al. (2016) found that baseline systolic and diastolic blood pressure levels were lower in their study population, with further changes occurring during the fasting period. Notably, this study highlighted the role of physical activity in influencing these outcomes, particularly in reducing triglyceride levels among participants engaging in moderate to high levels of physical activity.

Several studies reported significant variations in caloric intake during Ramadan, which may partially explain the heterogeneous results observed in lipid profiles. Maaloul et al. (2023) reported a substantial reduction in caloric intake (-722.5 kcal), while others such as Madkour et al. (2019) noted increases (+159.92 kcal). These variations in energy intake likely contribute to the different metabolic responses observed across studies.

The effects of Ramadan fasting on glycemic control have also shown varied results across different studies. Regarding fasting blood glucose (FBG), some studies reported significant increases during the fasting period. Al-Rawi et al. (2020) observed an elevation in FBG from 99.9 mg/dL pre-Ramadan to 105.7 mg/dL post-Ramadan in 47 overweight and obese males. Similarly, Faris et al. (2022) reported a significant increase in FBG during the Ramadan period in 25 individuals with obesity. However, other studies found reductions in FBG following Ramadan

fasting. Ismail et al. (2016) observed a greater reduction among participants with low physical activity levels, while Maaloul et al. (2023) and Ünalacak et al. (2011) also reported significant post-Ramadan decreases in FBG. Insulin dynamics during Ramadan fasting demonstrated notable variations across studies. Hasan et al. (2022) reported a significant increase in serum insulin levels by the end of Ramadan. This finding was corroborated by Kassab et al. (2003), who observed elevated insulin levels in both lean and obese subjects during the fasting period. The study found that insulin levels were consistently higher among obese subjects, suggesting that body composition may influence the metabolic response to Ramadan fasting.

Insulin resistance, as measured by the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), showed similarly mixed results. Hasan et al. (2022) documented an increase in HOMA-IR during Ramadan fasting, indicating a potential temporary decrease in insulin sensitivity. In contrast, Ünalacak et al. (2011) observed a significant reduction in HOMA-IR in the study group, while noting an increase in HOMA-IR in the control group. McNeil et al. (2014) reported no significant changes in metabolic parameters, maintaining stable glycemic control throughout Ramadan.

The heterogeneity in these findings might be attributed to various factors, including differences in study populations, fasting durations (ranging from 13 to 17 hours per day), geographical locations, and baseline characteristics of the participants. The studies encompassed diverse populations across multiple countries, including the UAE, Turkey, Tunisia, and Canada, with varying sample sizes and gender distributions. Additionally, baseline BMI values ranged from normal weight to obese categories ($18\text{-}45\text{ kg/m}^2$), which may have influenced the metabolic responses to Ramadan fasting.

Chapter 3 Methods

3.1 Methods for Specific Aim 1

Aim 1: To examine and compare physical activity, sleep, and mental health during the month of Ramadan among fasting participants in the United States and Saudi Arabia.

3.1.1 Participants and Setting

Based on a priori power analysis, a minimum of 658 participants was required for the cross-cultural study (Aim 1), with 329 participants to be recruited from the United States and 329 from Saudi Arabia. Recruitment occurred over two consecutive Ramadan seasons. During Ramadan 2024, participants residing in Saudi Arabia were recruited beginning in the second week of Ramadan and continuing through the end of the month. Participants were recruited primarily through digital platforms, with a focus on social media such as WhatsApp, Twitter, and Instagram. In addition, mass email campaigns were used to reach potential participants through several universities. During Ramadan 2025, we recruited participants residing in the United States, focusing on states with large Muslim populations. Inclusion criteria were: (1) self-identifying as a Muslim fasting during Ramadan, (2) being at least 18 years old, (3) being literate and having access to a smartphone, tablet, or computer to complete the Qualtrics survey, and (4) providing informed consent. Ethical approval for the study was obtained from the University of Michigan Institutional Review Board (HUM00244841) on February 19, 2024. All participants provided informed consent before completing the questionnaire.

Power Analysis

An estimated sample size for this study was determined using power analysis. Given that a small effect size (Cohen's $d = 0.25$) is expected, a significance level of $\alpha = 0.05$, and a power of 80% ($1 - \beta = 0.80$), the required sample size was calculated for independent t-tests. Using G*Power software, the analysis indicated that a minimum of 506 participants (253 per group) would be needed to detect statistically significant differences between the two groups. To account for potential dropouts and missing data, an additional 30% was added, resulting in a target sample size of approximately 658 participants (329 per group).

3.1.2 Data Collection

Data collection was conducted using a Qualtrics survey designed to gather comprehensive information about participants' physical activity, sleep, and mental health during Ramadan. Demographic questions, including age, gender, marital status, educational attainment, and country of residence, were included to provide contextual information. To ensure accessibility and inclusivity, all surveys were provided in both Arabic and English, catering to the linguistic preferences of participants in the United States and Saudi Arabia. This approach ensured that the instruments were culturally and linguistically appropriate for the target populations. The survey was distributed during the second and third weeks of Ramadan to allow participants sufficient time to adapt to the fasting schedule and associated lifestyle changes. Data were collected over a two-year period during Ramadan in 2024 and 2025, beginning in the second week of Ramadan each year. In the United States, data collection focused on states with large Muslim populations, including California, Texas, Florida, Michigan, New York, and Illinois, to ensure robust representation of the target demographic. In Saudi Arabia, recruitment efforts leveraged popular social media platforms, such as Twitter and WhatsApp, along with

mass email distribution to universities and large companies, to maximize outreach and participant engagement. Data collection was primarily conducted by the student investigator, with support from directors of Muslim community organizations, whose involvement facilitated participant recruitment, engagement, and logistical coordination across sites.

3.1.3 Outcomes

Physical Activity

The International Physical Activity Questionnaire (IPAQ) short form was used to assess Participants' physical activity levels (Craig et al., 2003) (A). The IPAQ short form has demonstrated acceptable test-retest reliability and validity (Lee et al., 2011). This questionnaire is suitable for individuals aged 15 to 69. It assesses three specific types of activities, including walking, moderate-intensity activity, and vigorous-intensity activity. The level of physical activity is expressed in terms of Metabolic Equivalent (MET). One MET represents the energy expended at rest, equivalent to an oxygen consumption of 3.5 ml/min/kg of body weight. Walking is rated at 3.3 METs, moderate activity at 4.0 METs, and vigorous activity at 8.0 METs. Physical activity levels are categorized as low, moderate, or high based on the formula: MET level $\times$ minutes of activity per day $\times$ days per week. The MET level is multiplied by the minutes of physical activity and the number of days per week. To be classified as having a high level of physical activity, respondents must engage in vigorous-intensity activity on at least three days, achieving a minimum of 1,500 MET-minutes per week, or participate in any combination of walking, moderate, or vigorous activities for seven or more days, reaching at least 3,000 MET-minutes per week. To be classified as having a moderate level of physical activity, respondents must participate in vigorous-intensity activity for at least 20 minutes on three or more days, engage in moderate-intensity activity or walking for at least 30 minutes on five or more days, or

do any combination of walking, moderate, or vigorous activities for five or more days, achieving at least 600 MET-minutes per week (Forde, 2018).

Sleep Patterns and Quality

Sleep patterns and quality were assessed using the Pittsburgh Sleep Quality Index (PSQI), a standardized and quantitative tool known for its high consistency, reliability, and validity (Backhaus et al., 2002; Buysse et al., 1989) (Appendix B). The PSQI consists of 19 self-reported questions divided into 7 components. These components are scored based on the algorithm developed by Buysse et al. (1989), with each component assigned a score on a 0–3 scale. Lower scores indicate no issues, while higher scores reflect progressively worsening issues. The seven components are subjective sleep quality (ranging from very good to very bad) sleep latency (from 15 minutes or less to over 60 minutes), sleep duration (from 7 or more hours to less than 5 hours), sleep efficiency (from 85% or more to less than 65% of sleep hours relative to time spent in bed), sleep disturbances (ranging from none to three or more times per week), use of sleep medications (from none to three or more times a week), and daytime dysfunction (ranging from not a problem to a very big problem). The scores for these seven components are summed to produce a global score, which can range from 0 to 21 and is treated as a continuous variable.

Anxiety

Anxiety level was assessed using the Generalized Anxiety Disorder-7 (GAD-7), a convenient self-report questionnaire commonly used in outpatient and primary care settings to screen for generalized anxiety disorder (GAD) (Appendix C). The GAD-7 was chosen for this study due to its strong reliability and its established criteria, construct, factorial, and procedural validity (Spitzer et al., 2006). According to the GAD-7, scores are categorized as follows: a score

of less than 5 indicates no minimal anxiety symptoms, 5 to 9 indicates mild anxiety, 10 to 14 indicates moderate anxiety, and a score of 15 or higher indicates severe anxiety.

Mental Well-Being

Positive mental health and well-being were assessed using the 14-item Mental Health Continuum–Short Form (MHC-SF), which was derived from the original 40-item scale (Appendix D). The MHC-SF includes three subscales: emotional well-being (three items), social well-being (five items), and psychological well-being (six items). Emotional well-being reflects positive emotions and satisfaction with life, social well-being assesses participants' functioning and connectedness within society, and psychological well-being evaluates positive individual functioning, such as self-acceptance, personal growth, and purpose in life. Participants indicated how frequently they had experienced each feeling during the past month using a six-point Likert scale ranging from 0 ("never") to 5 ("every day"). Responses across the 14 items were made to produce a total score ranging from 0 to 70, with higher scores indicating greater positive mental health. Participants were also classified as flourishing, moderately mentally healthy, or languishing. Flourishing required experiencing at least one indicator of emotional well-being and at least six indicators of social or psychological well-being "almost every day" or "every day." Languishing required experiencing at least one indicator of emotional well-being and at least six indicators of social or psychological well-being "never" or "once or twice" during the past month. Participants who met neither criterion were classified as moderately mentally healthy. The MHC-SF has demonstrated strong internal consistency and discriminant validity (Keyes, 2009), with a test-retest reliability of $r = .68$ after three months and $r = .65$ after nine months (Lamers et al., 2011).

3.1.4 Statistical Analysis

Data were analyzed using SPSS statistical software (version 29.1, SPSS Inc., Chicago, IL, USA). The dataset was screened for duplicate submissions, ineligible or substantially incomplete cases, out-of-range values, and missing responses. Cases lacking sufficient information to determine eligibility or calculate the primary questionnaire scores were excluded. For retained cases, missing item-level data were handled according to the scoring instructions for each questionnaire. Each statistical analysis included participants with complete data for the variables involved, and no missing values were imputed. Descriptive statistics, including means, standard deviations, and frequencies, were calculated to summarize demographic characteristics and outcomes variables. Cross-cultural comparisons between the U.S. and Saudi samples were conducted using independent samples t-tests for continuous variables and chi-square tests for categorical variables. Normality of the data was assessed using the Shapiro-Wilk test, and nonparametric alternatives (e.g., the Mann-Whitney U test) were employed for variables that violated normality assumptions. Statistical significance was set at $p \leq 0.05$.

3.2 Methods for Specific Aims 2 and 3

Aim 2: To investigate the effect of Ramadan fasting combined with five weekly 30-minute sessions of moderate-intensity aerobic exercise over four weeks on body composition and energy expenditure in 15 metabolically healthy adults with overweight and obesity.

Aim 3: To investigate the effect of Ramadan fasting combined with five weekly 30-minute sessions of moderate-intensity aerobic exercise over four weeks on lipids profile, glycemic control markers, and blood pressure in metabolically healthy adults with overweight and obesity.

3.2.1 Participants and Setting

Seventy-two interested individuals completed the initial eligibility questionnaire. Of these, 32, who met the preliminary eligibility criteria, proceeded to a comprehensive baseline assessment. Recruitment was conducted in the Detroit Metropolitan Area through flyers posted at Islamic centers and mosques and through announcements on social media platforms, including WhatsApp, Facebook, and Instagram (Appendix E). The recruitment flyer included a barcode linked to a screening questionnaire that collected general health information to assess participants' eligibility (Appendix F). Potential participants were contacted through their preferred method for a detailed explanation of the trial and confirmation of their initial eligibility (Appendices G & H). Those who met the inclusion criteria and agreed to participate were scheduled for a baseline visit lasting approximately one and a half hours.

Participants were eligible for inclusion if they were aged 18 to 65 years, were physically capable of fasting and exercising, and had committed to observing Ramadan fasting. Exclusion criteria included a history of metabolic, cardiovascular, cerebrovascular, renal, or hematological disease, cancer, or other conditions affecting metabolism. Additional exclusion criteria were current smoking, active dieting, and a body mass index (BMI) outside the range of 27 to 40 kg/m². Informed consent was obtained from all participants before the baseline visit (Appendix I).

3.2.2 Sample Size Calculation

Sample size was calculated based on the observed effect size ($d = 0.32$) for changes in body weight from a pilot study conducted in Physical Activity and Health laboratory during Ramadan 2023. Using G*Power for a repeated-measures, within-between interaction design with two groups (fasting-only and fasting plus exercise) and two time points (pre- and post-Ramadan),

an alpha level of 0.05 and statistical power of 0.80 were specified, yielding a required sample size of 24 participants. To account for an anticipated 20% dropout rate, 30 participants were recruited, with 15 allocated to each group.

3.2.3 Study Design and Randomization

This study used a two-arm, randomized controlled trial (RCT) design with parallel groups and a 1:1 allocation ratio to assess the effects of Ramadan diurnal intermittent fasting (RDF) and Ramadan fasting combined with moderate-intensity continuous training (RDF-EX) on cardiometabolic health in metabolically healthy individuals with overweight and obesity (Figure 1). Eligible participants were stratified by age and BMI to ensure between-group homogeneity. After baseline assessments, participants within each stratum were assigned to the Ramadan diurnal intermittent fasting combined with exercise group (RDF-EX) or the Ramadan diurnal intermittent fasting only group (RDF). The trial was conducted between February and April 2026. Ramadan began on 17 Feb 2026 and ended on the evening of 19 March 2026. The Consolidated Standards of Reporting Trials (CONSORT) statement was used as a framework for developing the study methodology (Moher et al., 2001) (Appendix J). The protocol was approved by the University of Michigan Institutional Review Board of Health and Behavioral Sciences (HUM00247761) and was registered on ClinicalTrials.gov (NCT07471646).

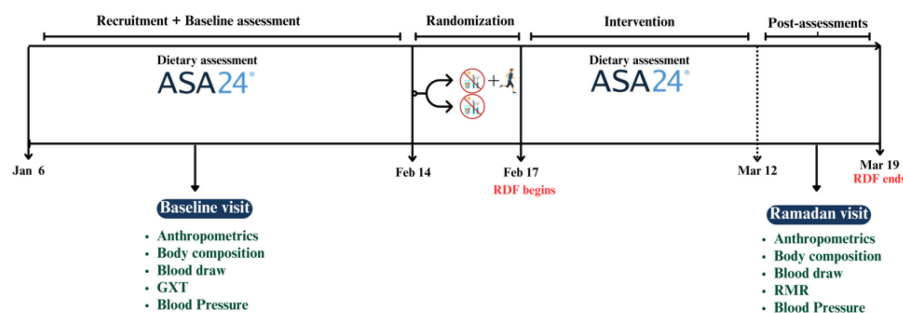


Figure 1. Study design

3.2.4 Exercise Intervention

Objective of the intervention

The primary objective of this 4-week intervention was to implement a structured moderate-intensity aerobic exercise program during the month of Ramadan, designed in accordance with the FITT principles (Frequency, Intensity, Time, and Type) as outlined by the American College of Sports Medicine (ACSM) guidelines (Liguori & American College of Sports, 2020). Participants had the option to exercise at the University of Michigan School of Kinesiology fitness center or at home to ensure study compliance and flexibility.

Intervention implementation

Participants were engaged in 30-minute moderate-intensity aerobic exercise sessions, five sessions per week, amounting to a total of twenty 30-minute exercise sessions over the 4-week intervention period. The exercise intensity was set at a moderate level, corresponding to 65–75% of each participant's baseline heart rate peak (HRpeak), as determined by a baseline graded exercise test (GXT) and in accordance with the ACSM Guidelines for Exercise Testing and Prescription (Ozemek et al., 2025). To ensure safety and gradual adaptation, participants began at 65% of their HRpeak during the first week, and intensity was increased by 5% each week until reaching 75% by the final week of the intervention. This progressive approach was designed to accommodate participants who may have been relatively sedentary at baseline. The duration of each exercise session was set at 40 minutes, structured to maximize effectiveness while ensuring safety and adherence. Each session began with 5 minutes of dynamic stretching to prepare the body for activity, followed by 30 minutes of moderate-intensity aerobic exercise, and concluded with 5 minutes of cool-down dynamic stretching. The type or mode of exercise focused on

aerobic activities. Participants were asked to engage in exercises such as treadmill walking or running, stationary cycling, or using elliptical machines, all of which are low-impact and suitable for individuals with varying fitness levels. For participants who choose to exercise at home or their preferred location, acceptable alternative modes of aerobic activity included brisk walking, jogging, or home-based workouts such as dance, step exercises, or online fitness classes. Detailed instructions and guidelines for these activities were provided (Appendix K).

Exercise adherence

Each participant was provided with a POLAR heart rate monitor to track exercise intensity, duration, and frequency, ensuring compliance with the target heart rate range (65–75% of HRpeak), the prescribed 30-minute session length, and the number of sessions per week. A participant was deemed adherent to the exercise program if they completed a minimum of 80% of the prescribed sessions during the 4-week intervention, corresponding to 16 out of the 20 scheduled sessions. To facilitate adherence tracking, participants exported data from the POLAR app after each session and shared it with a trained researcher.

Safety

Safety was a top priority for the exercise intervention, particularly since exercise sessions were scheduled one hour before breaking the fast and were performed in a dry fasting state. To ensure participant safety, three key mechanisms were implemented:

Pre-Exercise Hydration Assessment: Each participant was provided with a urine specific gravity test strip as a practical screening tool to identify potential inadequate hydration. To use the strip, participants were asked to immerse it in a urine sample and observe the reagent pad as it changed color within approximately 45 seconds. These test strips provided clear, easy-to-read

results in under 2 minutes, allowing participants to assess their hydration status before each exercise session promptly. This objective measurement helped detect potential dehydration and enabled participants to make informed decisions about their readiness to exercise.

Fluid Replacement Guidance: Participants were instructed to measure their body weight before and after each exercise session. Any weight loss observed post-exercise was considered fluid loss, and participants were advised to drink approximately 1.5 liters of fluid for each kilogram of body weight lost (Shirreffs & Maughan, 1998).

Nutritional Support: A list of electrolyte-rich and high-water-content foods was provided to participants. They were encouraged to incorporate these foods into their meals during the non-fasting period to maintain electrolyte balance and hydration levels.

3.2.5 Procedures

Participants were scheduled for baseline metabolic assessments approximately one month prior to the beginning of Ramadan. Assessments were conducted in the morning between 6:30 and 11:30 a.m. following an 8–10-hour overnight fast, during which only water was permitted. Participants were instructed to avoid caffeine and moderate-to-vigorous physical activity for at least 24 hours before testing and to arrive in a rested state to minimize acute influences on metabolic measurements. The baseline assessment lasted approximately 90 minutes and included body composition analysis, hemodynamic assessment, blood draw, resting metabolic rate (RMR) measurement, and graded exercise testing (GXT). During the last week of Ramadan, participants were scheduled for a fasting assessment, which followed the same procedures as the baseline assessment, except for the graded exercise test, and lasted approximately 75 minutes. To account for individual variability in the timing of the last meal during Ramadan, participants were asked

to report to the laboratory 8–10 hours after their most recent meal. Scheduling was organized in an overlapping manner to ensure efficient use of laboratory resources while accommodating participant availability.

Graded Exercise Test

Peak heart rate (HR_{peak}) was assessed using a graded exercise test (GXT) on a motorized treadmill and monitored with a metabolic cart (Quark CPET, COSMED, Italy) following the modified Bruce protocol (Bruce et al., 1973). The modified protocol was chosen because it starts at a lower workload than the standard Bruce protocol and is typically used for patients who are deconditioned, elderly, or sedentary and may not be able to keep pace with the faster standard protocol. The test began with two low-intensity warm-up stages (1.7 mph/0% grade and 1.7 mph/5% grade) before progressing through the standard incremental 3-minute stages of increasing speed and grade. Heart rate was continuously monitored throughout using a chest strap heart rate monitor, and the test was terminated at volitional exhaustion or participant-reported symptoms warranting cessation. The highest heart rate recorded during the final stage was recorded as HR_{peak}.

3.2.6 Outcome Variables

Sociodemographic characteristics such as age, sex, marital status, educational level, and employment were collected at baseline. Outcome variables were measured at two time points: a month before Ramadan (baseline) and during the last week of Ramadan. Body weight and fat mass were designated as the primary outcomes; all other body composition, metabolic, glycemic, lipid, blood pressure, and inflammatory outcomes were designated as secondary outcomes. MCP-1 was designated as an exploratory outcome.

Anthropometric and Hemodynamic Assessments

Anthropometric measures included height, weight, BMI, waist circumference, hip circumference, blood pressure, and heart rate. Height and weight were measured using a digital scale (Seca 700 scale) with participants maintaining a normal straight posture and wearing minimal clothing. Body weight and height were recorded to the nearest 0.1 cm. Waist circumference was measured using a measuring tape positioned in the horizontal plane exactly midway between the iliac crest and the costal arch (Riebe et al., 2018). Blood pressure and heart rate were assessed using an automatic sphygmomanometer (Adview®9000 modular diagnostic station, American Diagnostic Corporation ADC, NY, USA). Two measurements were taken one minute apart. If the systolic or diastolic blood pressure readings differed by 10 mmHg or more, a third measurement was performed, and the mean score of the two closest values was calculated and recorded.

Body Composition

Body composition, including fat mass (FM), fat-free mass (FFM), and percent body fat (PBF), was assessed using a Dual Energy X-Ray Absorptiometry (DEXA) scan (Lunar DPX DEXA scanner, GE, WI). Prior to each scan, the device was calibrated with a body composition block. Participants were instructed to lie in a supine position for approximately 10 minutes while remaining still. All DEXA scans were performed and interpreted by the same certified research staff to ensure consistency.

Resting Metabolic Rate (RMR)

RMR was measured by indirect calorimetry using a Parvo Medics TrueOne® 2400 metabolic cart equipped with a ventilated canopy (Parvo Medics, Salt Lake City, UT, USA). The

system continuously measured oxygen consumption (VO_2) and carbon dioxide production (VCO_2), from which RMR and respiratory exchange ratio were calculated. Participants were instructed to rest in a supine position during all sessions while RMR is recorded under a canopy in a thermo-neutral environment ($22\text{--}24^\circ\text{C}$) with dimmed lights. RMR was measured during the month before Ramadan and a week following the month of Ramadan for both RDF and RDF-EX groups. Measurements were conducted in the morning between 7:00 and 11:00 a.m. for a duration of 45 minutes, following an overnight fast (10-12 hours), with water being the only exception. Participants were also instructed to avoid physical activity for 12 hours prior to arriving at the laboratory.

Blood Sampling and Biochemical Analysis

Following a 10–12-hour overnight fast, 10 mL of venous blood was collected from each participant, including 6 mL in an EDTA tube and 4 mL in a serum-separator tube (SST). To standardize fasting duration and minimize variation related to collection time and recent dietary intake, samples were collected between 7:00 a.m. and 11:00 a.m. at both the pre- and post-intervention visits. Before centrifugation, 40 μL of whole blood from the EDTA tube was used to measure fasting glucose and the lipid profile, including total cholesterol, high-density lipoprotein cholesterol, and triglycerides, using a Cholestech LDX analyzer (Abbott Laboratories, Abbott Park, IL, USA). An additional whole-blood aliquot was used to measure glycated hemoglobin using an Abbott Afinion analyzer. Low-density lipoprotein cholesterol was calculated using the Friedewald equation (Friedewald et al., 1972). The remaining EDTA blood was centrifuged immediately at 3,000 rpm for 10 minutes at 4°C . The SST was allowed to clot at room temperature for 30 minutes and was subsequently centrifuged at 3,500 rpm at room temperature. Plasma and serum were aliquoted, labeled with unique participant codes, and stored at -80°C

until biochemical analysis. Fasting insulin and glycated serum protein were measured using commercially available assay kits from Crystal Chem (Elk Grove Village, IL, USA), whereas monocyte chemoattractant protein-1 (MCP-1) was measured using an enzyme-linked immunosorbent assay kit from R&D Systems (Minneapolis, MN, USA). Fasting insulin and glycated serum protein were assayed in duplicate, and the intra-assay coefficient of variation (CV) was calculated for each sample as $(SD/mean) \times 100$. The mean intra-assay CV was 5.5% for fasting insulin and 6.0% for glycated serum protein. MCP-1 was measured in a single replicate per sample; therefore, intra-assay CV could not be calculated for this analyte. Because all samples for each analyte were measured within a single analytical run, the inter-assay (between-run) CV was not estimable for any of the three analytes in the present study. The homeostatic model assessment of insulin resistance and quantitative insulin sensitivity check index were calculated from fasting glucose and insulin concentrations (Matthews et al., 1985).

Dietary Assessment

Dietary intake was assessed using the National Cancer Institute's Automated Self-Administered 24-Hour Dietary Assessment Tool (ASA24) at two timepoints. Participants completed one recall at any point during the baseline period before Ramadan and one recall at any point during Ramadan. Through the web-based platform, participants reported all foods and beverages consumed during the preceding 24 hours. The system provided written and audio instructions, portion-size images, and repeated prompts for commonly omitted items, such as condiments, beverages, and added fats. The ASA24 has demonstrated measurement performance comparable to interviewer-administered dietary recalls while offering a more cost-effective approach (Subar et al., (2012)). Dietary data were collected to characterize changes in total energy

and macronutrient intake during Ramadan and to determine whether intake differed between the fasting-only and fasting-plus-exercise groups

3.2.7 Statistical Analysis

All data were analyzed using SPSS statistical software (version 29.1, SPSS Inc., Chicago, IL, USA). Data were first examined for normality using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots. For all study outcomes, changes over time and differences between groups were evaluated using a two-way repeated-measures ANOVA, with time as the within-subject factor, intervention group as the between-subject factor, and baseline fat mass included as a covariate because it differed significantly between groups at baseline. This approach was applied consistently across all outcome domains. Adjusted estimated marginal means were calculated at the overall mean baseline fat mass, and pairwise comparisons were adjusted for multiple testing using the Bonferroni correction. Homogeneity of error variances was assessed using Levene's test, and effect sizes were reported as partial eta squared (η^2). Because dietary energy intake served as a secondary measure of intervention adherence rather than a primary study outcome, within-group changes in energy intake from pre- to post-intervention were assessed separately for each group (RDF and RDF+EX) using paired-samples t-tests. Statistical significance was set at $p < .05$. Graphical visualizations were created using GraphPad Prism (GraphPad Software, Boston, MA, USA)

Chapter 4 Results

4.1 Aim 1: Results

4.1.1 Participant Characteristics

A total of 1,399 participants were included in the analyses, comprising 1,115 residents of Saudi Arabia (KSA) and 284 residents of the United States (USA). Participant characteristics are presented in Table 1. The groups were comparable in age ($p = .074$) and in working status ($p = .695$). They differed, however, in body mass index, which was higher among KSA participants (25.7 ± 5.7 vs. 24.3 ± 4.5 kg/m², $p < .001$), and in sex distribution, with the KSA sample being predominantly male (74.2%) and the USA sample predominantly female (54.9%; $p < .001$).

Table 1. Demographic and health characteristics of participants observing Ramadan in Saudi Arabia and the United States

Characteristic	KSA (n = 1,115)	USA (n = 284)	p
Age (years)	29.2 $\pm$ 12.9	30.5 $\pm$ 11.2	.074
BMI (kg/m ²)	25.7 $\pm$ 5.7	24.3 $\pm$ 4.5	< .001
Weight (kg)	74.3 $\pm$ 19.3	68.7 $\pm$ 15.7	< .001
Height (cm)	169.5 $\pm$ 9.0	167.7 $\pm$ 11.2	.014
Gender, n (%)			< .001
Male	827 (74.2)	128 (45.1)	
Female	288 (25.8)	156 (54.9)	
Working status, n (%)			.695
Student	575 (51.6)	149 (52.5)	
Employee (full/part-time)	413 (37.0)	101 (35.6)	
Retired or on leave	56 (5.0)	11 (3.9)	
Freelancer	20 (1.8)	5 (1.8)	
Unemployed	51 (4.6)	18 (6.3)	

Values are reported as mean $\pm$ SD or n (%). KSA = Kingdom of Saudi Arabia; USA = United States of America; BMI = body mass index.

4.1.2 Physical Activity

Physical activity and sedentary behavior are summarized in Table 2. KSA participants reported significantly higher vigorous-intensity physical activity (191.95 ± 176.17 vs. 136.59 ± 128.28 min/week; $t_{(247.52)} = 4.220, p < .001, d = 0.33$) and significantly more time spent walking (402.46 ± 361.66 vs. 343.67 ± 325.99 min/week; $t_{(401.18)} = 2.408, p = .017, d = 0.17$) than USA participants. Moderate-intensity physical activity did not differ significantly between groups ($t_{(283.19)} = 0.608, p = .544$). In contrast, USA participants reported significantly greater daily sitting time than KSA participants (363.10 ± 213.52 vs. 326.28 ± 246.52 min/day; $t_{(423.59)} = -2.343, p = .020, d = -0.15$). Together, KSA participants reported greater vigorous-intensity physical activity and walking and less sedentary time during Ramadan than USA participants. These unadjusted, self-reported differences should be interpreted cautiously because the groups differed in sex distribution and BMI.

Table 2. Self-reported physical activity and sedentary behavior during Ramadan among participants in Saudi Arabia and the United States

Variable	KSA M $\pm$ SD	USA M $\pm$ SD	t	df	p	Cohen's d
Vigorous PA (min/wk)	191.95 $\pm$ 176.17	136.59 $\pm$ 128.28	4.220	247.52	< .001	0.33
Moderate PA (min/wk)	275.16 $\pm$ 269.58	261.76 $\pm$ 257.99	0.608	283.19	.544	0.05
Walking (min/wk)	402.46 $\pm$ 361.66	343.67 $\pm$ 325.99	2.408	401.18	.017	0.17
Sitting (min/day)	326.28 $\pm$ 246.52	363.10 $\pm$ 213.52	-2.343	423.59	.020	-0.15

Values are reported as mean $\pm$ SD

4.1.3 Sleep

Sleep timing and sleep characteristics are reported in Table 3. KSA participants went to bed significantly later ($2:55$ AM $\pm$ 1.80 h vs. $12:23$ AM $\pm$ 1.70 h; $t_{(364.25)} = 17.126, p < .001, d = 1.42$) and woke significantly later ($10:33$ AM $\pm$ 2.12 h vs. $7:27$ AM $\pm$ 2.50 h; $t_{(282.72)} = 15.446, p < .001, d = 1.40$) than USA participants, with both differences representing large effects. Sleep-

onset latency also differed significantly between groups ($\chi^2_{(3)} = 11.960, p = .008, V = .10$); USA participants more frequently reported falling asleep within 15 minutes (46.4% vs. 36.6%), whereas KSA participants more commonly required 15 to 30 minutes. Sleep duration differed significantly as well ($\chi^2_{(3)} = 12.841, p = .005, V = .11$), with a higher proportion of KSA participants sleeping more than seven hours (36.9% vs. 29.5%) and more USA participants sleeping five to six hours (35.7% vs. 24.2%). Subjective sleep quality also differed significantly between countries ($\chi^2_{(3)} = 19.037, p < .001, V = .13$). USA participants were more likely to report their sleep as fairly good (51.3% vs. 37.9%) compared to KSA participants, whereas KSA participants reported a higher prevalence of very bad sleep (16.0% vs. 7.1%) compared to USA participants.

Table 3. Sleep timing, sleep quality, and sleep-quality classification during Ramadan among participants in Saudi Arabia and the United States

Sleep timing	KSA M ± SD	USA M ± SD	t	df	P	Cohen's d
Bedtime (hh:mm)	2:55 am ± 1.80	12:23 am ± 1.70	17.126	364.25	< .001	1.42
Wake time (hh:mm)	10:33 am ± 2.12	7:27 am ± 2.50	15.446	282.72	< .001	1.40
Sleep characteristic	KSA n (%)	USA n (%)	χ^2	df	P	Cramér's V
Sleep latency			11.960	3	.008	.10
< 15 min	339 (36.6)	104 (46.4)				
15–30 min	392 (42.3)	68 (30.4)				
31–60 min	132 (14.3)	38 (17.0)				
> 60 min	63 (6.8)	14 (6.2)				
Sleep duration			12.841	3	.005	.11
< 5 h	96 (10.4)	19 (8.5)				
5–6 h	224 (24.2)	80 (35.7)				
6–7 h	264 (28.5)	59 (26.3)				
> 7 h	342 (36.9)	66 (29.5)				
Sleep quality			19.037	3	< .001	.13
Very good	157 (17.0)	37 (16.5)				
Fairly good	351 (37.9)	115 (51.3)				
Fairly bad	270 (29.2)	56 (25.0)				
Very bad	148 (16.0)	16 (7.1)				

Values are presented as mean $\pm$ SD or n (%). Sleep times were analyzed on a continuous decimal scale, with post-midnight times coded beyond 24:00

4.1.4 Mental Health and Well-Being

Anxiety and mental health outcomes are presented in Table 4. The distribution of anxiety severity differed significantly between groups ($\chi^2_{(3)} = 10.148, p = .017, V = .10$). 61.8% of USA participants were classified in the minimal-anxiety category, compared with 49.8% of KSA participants in this category. KSA participants showed a higher prevalence of mild anxiety (33.4%), than USA participants (24.5%), with broadly similar proportions in the moderate- and severe-anxiety categories

A parallel pattern emerged for mental well-being ($\chi^2_{(2)} = 25.429, p < .001, V = .15$). USA participants were considerably more likely to be classified as flourishing (65.0% vs. 47.9%), whereas languishing was more than three times as prevalent among KSA participants (12.7% vs. 3.7%). Thus, despite being more physically active, KSA participants reported poorer sleep quality, higher anxiety, and lower positive mental health than their USA counterparts.

Table 4. Anxiety symptoms and positive mental health during Ramadan among participants in Saudi Arabia and the United States

Category	KSA n (%)	USA n (%)	χ^2	df	P	Cramér's V
Anxiety (GAD-7)			10.148	3	.017	.10
Minimal	442 (49.8)	131 (61.8)				
Mild	297 (33.4)	52 (24.5)				
Moderate	98 (11.0)	20 (9.4)				
Severe	51 (5.7)	9 (4.2)				
Mental well-being (MHC-SF)			25.429	2	< .001	.15
Languishing	113 (12.7)	8 (3.7)				
Moderately mentally healthy	349 (39.3)	67 (31.3)				
Flourishing	425 (47.9)	139 (65.0)				

Values are number and percentage n (%).

4.2 Aim 2 and Aim 3: Results

4.2.1 Overall Results

4.2.1.1 Participant Characteristics

A total of 27 healthy adults with overweight or obesity completed the trial, including 14 participants assigned to the Ramadan fasting-only group (RDF) and 13 assigned to the Ramadan fasting-plus-exercise group (RDF+EX). Participants baseline characteristics are presented in Table 5. The sample comprised 16 men and 11 women, distributed similarly across the two groups (RDF, 57.1% male; RDF+EX, 61.5% male). Participants were of comparable age (31.8 ± 7.2 and 36.6 ± 11.2 years for RDF and RDF+EX, respectively) and were classified as overweight to obese on the basis of body mass index (33.3 ± 5.7 and 31.2 ± 4.7 kg/m²). The groups did not differ significantly in age, body mass index, body weight, lean mass, body-fat percentage, glycated hemoglobin, resting metabolic rate, or maximal oxygen uptake (all $p > .05$). However, participants in the RDF group had significantly greater baseline fat mass than those in the RDF+EX group (41.1 ± 13.4 vs. 31.5 ± 9.9 kg; $p = .046$). The RDF group also had a higher mean body-fat percentage, although the difference was not statistically significant ($42.8 \pm 8.8\%$ vs. $36.9 \pm 7.0\%$; $p = .064$).

Table 5. Baseline characteristics of participants by group.

Characteristic	RDF (n = 14)	RDF+EX (n = 13)	P
Sex (male/female), n	8 / 6	8 / 5	—
Age (years)	31.8 ± 7.2	36.6 ± 11.2	.190
Body mass index (kg/m ²)	33.3 ± 5.7	31.2 ± 4.7	.323
Body weight (kg)	97.4 ± 17.1	87.1 ± 15.3	.113
Fat mass (kg)	41.1 ± 13.4	31.5 ± 9.9	.046*
Lean mass (kg)	53.3 ± 8.8	52.7 ± 8.3	.857
Body fat (%)	42.8 ± 8.8	36.9 ± 7.0	.064
HbA1c (%)	5.4 ± 0.2	5.3 ± 0.4	.621
RMR (kcal/day)	1840.1 ± 260.1	1750.6 ± 221.4	.347

VO ₂ peak (L/min)	2.6 ± 0.6	2.6 ± 0.4	.933
VO ₂ peak (mL/kg/min)	30.5 ± 7.4	28.3 ± 6.7	.423

Values are mean ± SD

4.2.1.2 Exercise Adherence and Dietary Monitoring

Adherence to the prescribed aerobic exercise intervention was monitored across all four weeks in the RDF+EX group (n = 13) based on session frequency and exercise intensity assessed using POLAR heart-rate monitors (Figure 2). Participants completed 182 of the 260 prescribed sessions, corresponding to an overall attendance rate of 70.0%. Weekly session frequency remained below the prescribed five sessions per week, averaging 3.5 ± 0.7 , 3.6 ± 0.8 , 3.7 ± 0.5 , and 3.2 ± 0.9 sessions during Weeks 1 through 4, respectively, with the lowest frequency observed during the final week. Each completed 40-minute session consisting of a 5-minute warm-up, 30 minutes of moderate-intensity aerobic exercise, and a 5-minute cool-down. Based on the achieved session frequency, participants completed approximately 105 minutes per week of moderate-intensity aerobic exercise, representing 70% of the prescribed 150-minute weekly aerobic dose. Mean heart rate during the 30-minute aerobic bout remained within the prescribed moderate-intensity range across all four weeks ($69.8 \pm 2.4\%$, $70.0 \pm 1.8\%$, $70.2 \pm 1.4\%$, and $70.7 \pm 1.7\%$ HRpeak; 100.2% of the intensity target). Thus, adherence to the prescribed exercise intensity was high during completed sessions, whereas adherence to the prescribed weekly session frequency was lower. This pattern suggests that completing five sessions per week during Ramadan was the primary challenge for feasibility.

As dietary intake was not controlled during the intervention, 24-hour dietary recalls were obtained before and during Ramadan to characterize energy and macronutrient intake (Table 6). Complete recalls were available for 25 participants (RDF, n = 13; RDF+EX, n = 12). Both groups significantly reduced daily energy intake during Ramadan relative to baseline (RDF:

2625 $\pm$ 483 to 1982 $\pm$ 437 kcal/day, a reduction of 643 kcal/day, $p = .004$; RDF+EX: 2565 $\pm$ 255 to 2034 $\pm$ 699 kcal/day, a reduction of 531 kcal/day, $p = .017$). The relative macronutrient distribution was similar between groups and remained broadly stable from before to during Ramadan, with carbohydrate contributing approximately 42%, fat 38–40%, and protein 18–19% of total energy intake at both timepoints. Collectively, these findings indicate that, despite the absence of dietary control, the two groups did not differ appreciably in energy or macronutrient intake, reducing the likelihood that between-group differences in the measured outcomes were attributable to differential dietary intake.

Table 6. Energy and macronutrient intake before and during Ramadan, by group.

Outcome	RDF			RDF+EX		
	<i>Pre</i>	<i>Post</i>	<i>p</i>	<i>Pre</i>	<i>Post</i>	<i>p</i>
Energy (kcal/day)	2625 $\pm$ 483	1982 $\pm$ 437	.004*	2565 $\pm$ 255	2034 $\pm$ 699	.017*
Carbohydrate (%)	42.6 $\pm$ 7.9	44.5 $\pm$ 10.4	.614	41.9 $\pm$ 7.5	40.0 $\pm$ 5.3	.551
Fat (%)	38.5 $\pm$ 5.9	36.6 $\pm$ 8.1	.582	40.4 $\pm$ 7.6	39.8 $\pm$ 3.5	.794
Protein (%)	18.8 $\pm$ 3.7	18.6 $\pm$ 5.0	.904	17.8 $\pm$ 4.2	19.7 $\pm$ 4.4	.255

Values are mean $\pm$ SD; Pre = before Ramadan, Post = during the last week of Ramadan. The p column within each group is the within-group paired-samples t -test

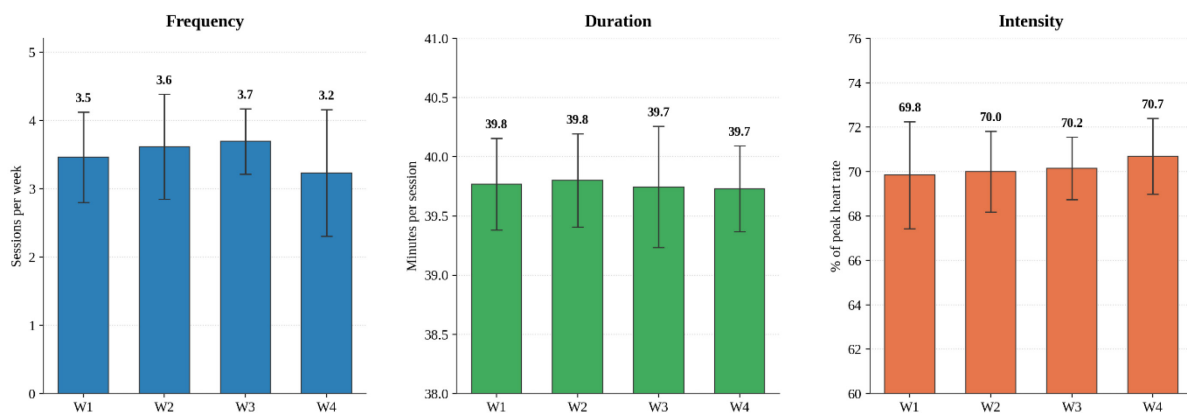


Figure 2. Weekly exercise adherence in the RDF+EX group (session frequency, duration, and intensity across Weeks 1–4).

4.2.2 Results Specific to Aim 2

4.2.2.1 Body Composition

As shown in Table 7, two-way repeated-measures ANOVA revealed that, for body weight, the main effects of time ($p = .751$) and group ($p = .999$) were non-significant, whereas the Group $\times$ Time interaction was significant, $F(1, 24) = 4.54, p = .044, \eta^2 = .159$, reflecting a decrease in the RDF+EX group (87.1 ± 15.3 to 86.2 ± 15.4 kg) alongside a slight increase in the RDF group (97.4 ± 17.1 to 97.9 ± 17.2 kg); neither within-group change was significant (RDF $p = .294$; RDF+EX $p = .069$). For waist circumference, the main effects of time ($p = .712$) and group ($p = .362$) and the interaction ($p = .754$) were non-significant. For fat mass, the main effect of time was non-significant ($p = .184$), whereas the main effect of group was significant, $F(1, 25) = 4.87, p = .037, \eta^2 = .163$, with lower values in the RDF+EX group (31.5 ± 9.9 kg) than the RDF group (41.1 ± 13.4 kg), and the Group $\times$ Time interaction was significant, $F(1, 25) = 4.60, p = .042, \eta^2 = .155$, reflecting a decrease in the RDF+EX group (31.5 ± 9.9 to 30.7 ± 9.9 kg; within-group $p = .012$) with no significant change in the RDF group ($p = .630$).

Fat-free mass showed no significant main effect of time ($p = .520$), group ($p = .896$), or interaction ($p = .309$). Lean mass likewise showed no significant main effect of time ($p = .498$), group ($p = .885$), or interaction ($p = .306$). For percent body fat, the main effects of time ($p = .272$) and group ($p = .718$) and the interaction ($p = .326$) were non-significant; however, the within-group comparison was significant in the RDF+EX group, which decreased from $36.9 \pm 7.0\%$ to $36.3 \pm 7.2\%$ ($p = .036$), with no significant change in the RDF group ($p = .906$). For visceral fat, the main effects of time ($p = .390$) and group ($p = .080$) were non-significant, whereas the Group $\times$ Time interaction was significant, $F(1, 24) = 6.40, p = .018, \eta^2 = .210$,

reflecting a decrease in the RDF+EX group (1.2 ± 0.8 to 1.1 ± 0.7 kg) alongside an increase in the RDF group (1.0 ± 0.6 to 1.1 ± 0.6 kg); neither within-group change was significant (RDF $p = .396$; RDF+EX $p = .066$). Subcutaneous fat showed no significant main effect of time ($p = .365$), group ($p = .529$), or interaction ($p = .240$). Individual pre-to-post changes for body composition outcomes, by group, are presented in Appendix M.

Table 7. Changes in body composition following Ramadan diurnal fasting by group

Outcome	RDF (n=14)		RDF+EX (n=13)		Time Effect	Group	Interaction
	<i>Pre</i>	<i>Post</i>	<i>Pre</i>	<i>Post</i>	(F, p, ηp^2)	(F, p, ηp^2)	(F, p, ηp^2)
Weight (kg)	97.4 ± 17.1	97.9 ± 17.2	87.1 ± 15.3	86.2 ± 15.4	(0.10, .751, .004)	(0.00, .999, .000)	(4.54, .044, .159)*
WC (cm)	101.3 ± 16.9	100.4 ± 14.9	95.5 ± 15.6	93.6 ± 14.3	(0.14, .712, .006)	(0.87, .362, .035)	(0.10, .754, .004)
Fat mass (kg)	41.1 ± 13.4	41.3 ± 13.5	31.5 ± 9.9	30.7 ± 9.9	(1.87, .184, .070)	(4.87, .037, .163)*	(4.60, .042, .155)*
Fat-free mass (kg)	56.3 ± 9.1	56.6 ± 9.6	55.6 ± 8.8	55.5 ± 8.9	(0.43, .520, .017)	(0.02, .896, .001)	(1.08, .309, .043)
Lean mass (kg)	53.3 ± 8.8	53.7 ± 9.3	52.7 ± 8.3	52.6 ± 8.4	(0.47, .498, .019)	(0.02, .885, .001)	(1.10, .306, .044)
Body fat (%)	42.8 ± 8.8	42.8 ± 9.0	36.9 ± 7.0	36.3 ± 7.2	(1.26, .272, .050)	(0.13, .718, .006)	(1.01, .326, .040)
Visceral fat (kg)	1.0 ± 0.6	1.1 ± 0.6	1.2 ± 0.8	1.1 ± 0.7	(0.77, .390, .031)	(3.35, .080, .123)	(6.40, .018, .210)*
Subcutaneous fat (kg)	2.9 ± 1.4	2.9 ± 1.4	1.9 ± 0.9	1.8 ± 1.0	(0.85, .365, .034)	(0.41, .529, .017)	(1.46, .240, .057)

Values are presented as mean ± SD. Pre and Post represent baseline and post-intervention values

4.2.2.2 Resting Metabolic Rate

The analysis revealed that, for VO_2 , the main effects of time ($p = .935$) and group ($p = .935$) and the interaction ($p = .241$) were non-significant, with no significant within-group change in either group (RDF $p = .158$; RDF+EX $p = .665$). For VCO_2 , the main effects of time ($p = .983$) and group ($p = .634$) and the interaction ($p = .638$) were non-significant, with no significant within-group change in either group (RDF $p = .280$; RDF+EX $p = .147$). For respiratory quotient (RQ), the main effects of time ($p = .782$) and group ($p = .192$) and the interaction ($p = .608$) were non-significant; however, the within-group comparison was significant in the RDF group, which increased from 0.77 ± 0.04 to 0.82 ± 0.06 ($p = .033$), with no significant change in the RDF+EX group ($p = .210$). For RMR, the main effects of time ($p = .772$) and group ($p = .831$) and the interaction ($p = .337$) were non-significant, with no significant within-group change in either group (RDF $p = .326$; RDF+EX $p = .709$). REE showed the same pattern, with no significant main effect of time ($p = .771$), group ($p = .831$), or interaction ($p = .339$), and no significant within-group change in either group (RDF $p = .327$; RDF+EX $p = .712$). Full descriptive and inferential results are presented in Table 2.

Table 8. Changes in resting energy expenditure following Ramadan diurnal fasting

Outcome	RDF (n=14)			RDF+EX (n=13)			Time Effect (F, p, ηp^2)	Group (F, p, ηp^2)	(Interaction) (F, p, ηp^2)
	Pre	Post	p	Pre	Post	p			
VO ₂ (mL/min)	266.7 ± 37.0	258.2 ± 41.9	.158	253.9 ± 32.1	256.3 ± 30.6	.665	(0.01, .935, .000)	(0.01, .935, .000)	(1.44, .241, .057)
VCO ₂ (mL/min)	205.1 ± 32.5	211.6 ± 35.8	.280	194.3 ± 26.4	202.9 ± 19.1	.147	(0.00, .983, .000)	(0.23, .634, .010)	(0.23, .638, .009)
RQ	0.77 ± 0.04	0.82 ± 0.06	.033*	0.77 ± 0.04	0.80 ± 0.05	.210	(0.08, .782, .003)	(1.81, .192, .070)	(0.27, .608, .011)
RMR (kcal/day)	1840 ± 260	1802 ± 290	.326	1751 ± 221	1762 ± 229	.709	(0.09, .772, .004)	(0.05, .831, .002)	(0.96, .337, .038)
REE (kcal/day)	1823 ± 258	1785 ± 287	.327	1734 ± 219	1745 ± 228	.712	(0.09, .771, .004)	(0.05, .831, .002)	(0.95, .339, .038)

Values are presented as mean ± SD. Pre and Post represent baseline and post-intervention values

4.2.3 Results Specific to Aim 3

4.2.3.1 Cardiovascular Risk Markers

Two-way repeated-measures ANOVA revealed that, for total cholesterol, the main effects of time ($p = .782$) and group ($p = .245$) and the Group $\times$ Time interaction ($p = .638$) were non-significant, with no significant within-group change in either group (RDF $p = .973$; RDF+EX $p = .324$). For HDL cholesterol, the main effects of time ($p = .426$) and group ($p = .338$) and the interaction ($p = .258$) were non-significant, with no significant within-group change in either group (RDF $p = .385$; RDF+EX $p = .675$). For LDL cholesterol, the main effects of time ($p = .858$) and group ($p = .229$) and the interaction ($p = .732$) were non-significant, with no significant within-group change in either group (RDF $p = .953$; RDF+EX $p = .760$). For triglycerides, the main effects of time ($p = .944$) and group ($p = .950$) and the interaction ($p = .988$) were non-significant, with no significant within-group change in either group (RDF $p = .970$; RDF+EX $p = .905$). For systolic blood pressure, the main effects of time ($p = .948$) and group ($p = .359$) and the Group $\times$ Time interaction ($p = .180$) were non-significant; however, the within-group comparison was significant in the RDF+EX group, which decreased from 120.5 ± 15.3 to 113.2 ± 10.7 mmHg ($p = .046$), with no significant change in the RDF group ($p = .569$). For diastolic blood pressure, the main effects of time ($p = .322$) and group ($p = .628$) and the interaction ($p = .315$) were non-significant, with no significant within-group change in either group (RDF $p = .776$; RDF+EX $p = .528$). For resting heart rate, the main effects of time ($p = .967$) and group ($p = .742$) and the interaction ($p = .861$) were non-significant, with no significant within-group change in either group (RDF $p = .899$; RDF+EX $p = .746$).

Table 9. Changes in lipid profile, blood pressure, and resting heart rate following Ramadan diurnal fasting

Outcome	RDF (n=13)			RDF+EX (n=12)			Time Effect (F, p, η^2)	Group (F, p, η^2)	Interaction (F, p, η^2)
	Pre	Post	p	Pre	Post	p			
TC (mg/dL)	176.2 ± 26.4	176.0 ± 32.0	.973	189.3 ± 39.5	194.0 ± 41.2	.324	(0.08, .782, .004)	(1.42, .245, .061)	(0.23, .638, .010)
HDL-C (mg/dL)	48.2 ± 11.6	45.7 ± 9.2	.385	46.8 ± 8.0	47.7 ± 10.0	.675	(0.66, .426, .029)	(0.96, .338, .042)	(1.35, .258, .058)
LDL-C (mg/dL)	111.3 ± 27.5	111.7 ± 30.0	.953	124.1 ± 29.7	121.8 ± 37.1	.760	(0.03, .858, .001)	(1.53, .229, .065)	(0.12, .732, .005)
TRGs (mg/dL)	93.4 ± 37.3	93.8 ± 33.2	.970	93.5 ± 54.6	94.3 ± 45.7	.905	(0.01, .944, .000)	(0.00, .950, .000)	(0.00, .988, .000)
SBP (mmHg)	122.6 ± 10.5	120.8 ± 12.8	.569	120.5 ± 15.3	113.2 ± 10.7	.046*	(0.00, .948, .000)	(0.88, .359, .035)	(1.91, .180, .074)
DBP (mmHg)	72.4 ± 12.2	73.6 ± 10.7	.776	73.8 ± 14.4	71.6 ± 8.4	.528	(1.02, .322, .041)	(0.24, .628, .010)	(1.06, .315, .042)
RHR (bpm)	67.8 ± 9.1	68.1 ± 13.4	.899	65.2 ± 12.8	65.9 ± 11.6	.746	(0.00, .967, .000)	(0.11, .742, .005)	(0.03, .861, .001)

Values are presented as mean ± SD. Pre and Post represent baseline and post-intervention values

4.2.3.2 Glycemic Control

Two-way repeated-measures ANOVA revealed that, for fasting glucose, the main effects of time ($p = .499$) and group ($p = .737$) and the Group $\times$ Time interaction ($p = .762$) were non-significant, with no significant within-group change in either group (RDF $p = .197$; RDF+EX $p = .106$). For insulin, the main effects of time ($p = .772$) and group ($p = .563$) and the interaction ($p = .893$) were non-significant, with no significant within-group change in either group (RDF $p = .204$; RDF+EX $p = .491$). For glycated serum protein, the main effect of time was significant, $F(1, 22) = 6.15$, $p = .021$, $\eta^2 = .218$, reflecting an increase in both groups (RDF: 172.7 ± 39.2 to 207.1 ± 66.2 $\mu\text{mol/L}$; RDF+EX: 182.9 ± 23.7 to 218.9 ± 35.1 $\mu\text{mol/L}$), with significant within-group increases in both (RDF $p = .024$; RDF+EX $p < .001$); the main effect of group ($p = .563$) and the interaction ($p = .730$) were non-significant. For HbA1c, the main effects of time ($p = .391$) and group ($p = .863$) and the interaction ($p = .918$) were non-significant; however, within-group comparisons were significant in both groups, with decreases from 5.37 ± 0.21 to $5.25 \pm 0.25\%$ in the RDF group ($p = .001$) and from 5.31 ± 0.37 to $5.20 \pm 0.35\%$ in the RDF+EX group ($p = .020$). For HOMA-IR, the main effects of time ($p = .675$) and group ($p = .506$) and the interaction ($p = .866$) were non-significant, with no significant within-group change in either group (RDF $p = .122$; RDF+EX $p = .348$). For QUICKI, the main effects of time ($p = .707$) and group ($p = .499$) and the interaction ($p = .588$) were non-significant, with no significant within-group change in either group (RDF $p = .280$; RDF+EX $p = .188$). Full descriptive and inferential results are presented in Table 5.

Table 10. Changes in glycemic control and insulin-sensitivity markers following Ramadan diurnal fasting

Outcome	RDF			RDF+EX			Time Effect (F, p, η^2)	Group (F, p, η^2)	Interaction (F, p, η^2)
	Pre	Post	p	Pre	Post	p			
FBG (mg/dL)	97.6 ± 6.5	101.9 ± 11.9	.197	94.8 ± 8.4	100.8 ± 8.6	.106	(0.47, .499, .021)	(0.12, .737, .005)	(0.09, .762, .004)
Insulin (μ IU/mL)	11.8 ± 3.8	14.7 ± 7.8	.204	10.3 ± 5.4	12.5 ± 8.8	.491	(0.09, .772, .004)	(0.35, .563, .015)	(0.02, .893, .001)
GSP (μ mol/L)	172.7 ± 39.2	207.1 ± 66.2	.024*	182.9 ± 23.7	218.9 ± 35.1	<.001*	(6.15, .021, .218)	(0.35, .563, .015)	(0.12, .730, .006)
HbA1c (%)	5.37 ± 0.21	5.25 ± 0.25	.001*	5.31 ± 0.4	5.2 ± 0.3	.020*	(0.77, .391, .034)	(0.03, .863, .001)	(0.01, .918, .000)
HOMA-IR	2.85 ± 0.96	3.72 ± 2.03	.122	2.43 ± 1.3	3.08 ± 1.9	.348	(0.18, .675, .008)	(0.46, .506, .020)	(0.03, .866, .001)
QUICKI	0.33 ± 0.017	0.322 ± 0.02	.280	0.348 ± 0.04	0.334 ± 0.03	.188	(0.15, .707, .007)	(0.47, .499, .021)	(0.30, .588, .014)

Values are presented as mean ± SD. Pre and Post represent baseline and post-intervention values.

4.2.3.3 Inflammatory Marker (MCP-1)

Two-way repeated-measures ANOVA revealed that, for MCP-1, the main effect of time was significant, $F(1, 22) = 6.45$, $p = .019$, $\eta^2 = .227$, reflecting an increase in both groups (RDF: 75.1 ± 66.6 to 139.0 ± 37.4 pg/mL; RDF+EX: 55.5 ± 39.7 to 121.3 ± 45.3 pg/mL), with significant within-group increases in both (RDF $p = .028$; RDF+EX $p = .002$); the main effect of group ($p = .229$) and the Group $\times$ Time interaction ($p = .638$) were non-significant. Full descriptive and inferential results are presented in Table 6. Individual pre-to-post changes for cardiometabolic outcomes, by group, are presented in Appendix M.

Table 11. Changes in plasma monocyte chemoattractant protein-1 concentrations following Ramadan diurnal fasting

Outcome	RDF			RDF+EX			Time Effect (F, p, η^2)	Group (F, p, η^2)	Interaction (F, p, η^2)
	Pre	Post	p	Pre	Post	p			
MCP-1 (pg/mL)	75.1 $\pm$ 66.6	139.0 $\pm$ 37.4	.028*	55.5 $\pm$ 39.7	121.3 $\pm$ 45.3	.002*	(6.45, .019, .227)	(1.53, .229, .065)	(0.23, .638, .010)

Values are presented as mean $\pm$ SD. Pre and Post represent baseline and post-intervention values.

Chapter 5 Discussion

5.1 Discussion Pertaining to Aim 1

This study aimed to compare physical activity, sleep, anxiety, and mental health and well-being between Saudi Arabia (KSA) participants and the United States (USA) participants observing Ramadan. The findings suggest that the broader social and national setting in which Ramadan is observed may be associated with health-related behaviors and well-being. However, the study compared participants based on country of residence and did not directly measure cultural factors. Therefore, the observed differences should be interpreted as country-level associations rather than evidence that culture alone caused these differences or exerted a greater influence than Ramadan fasting itself. Contrary to the hypotheses, KSA participants reported more vigorous-intensity physical activity and walking and less sedentary time than USA participants; however, the self-reported moderate-intensity physical activity did not differ between groups. The hypothesis regarding sleep was partially supported. KSA participants reported poorer subjective sleep quality, as hypothesized; however, the findings did not support the expectation that they would have shorter sleep duration. The hypothesis regarding mental health was not supported for anxiety. KSA participants showed a lower prevalence of minimal anxiety and a higher prevalence of mild anxiety than USA participants. They were also less likely to be classified as flourishing and more likely to be classified as languishing.

Physical Activity and Sedentary Behaviors

KSA participants reported significantly higher vigorous-intensity activity and greater walking, comparable levels of moderate-intensity activity, and significantly lower daily sitting time, compared to USA participants. Inconsistent with existing literature, this study did not find the reduction in physical activity commonly reported during Ramadan. Several studies using objective measures of PA have reported a decline in PA level during Ramadan. For example, Farooq et al. (2021) observed a reduction in daily step counts during fasting. Similarly, Harder-Lauridsen et al. (2017), Kocaaga et al. (2019) and Lessan et al. (2018) documented decreases in daily steps or moderate-to-vigorous activity. Other studies with subjective measures have reported the opposite pattern, with activity increasing during or after the month (Ağaçdiken & Gökteş, 2023; Khan et al., 2017; Parkash et al., 2023).

Interpreting this pattern requires reference to habitual physical activity levels in the two countries, because the observed differences could otherwise reflect ordinary national differences rather than the influence of Ramadan. Population-level surveillance indicates that the opposite pattern prevails outside Ramadan. In a pooled analysis of 358 population-based surveys, (Guthold et al., 2018) estimated that insufficient physical activity affected 53% of adults in Saudi Arabia, compared with approximately 40% in the United States. More recent estimates continue to show a high prevalence in Saudi Arabia (Strain et al., 2024). The higher vigorous-intensity activity and lower sitting time reported by KSA participants in the present study therefore run counter to the direction that habitual national patterns would predict. This strengthens the interpretation that the observed differences are associated with the observance of Ramadan rather than with pre-existing differences between the two populations, although the cross-sectional design precludes a direct test of within-country change.

A plausible explanation for this inconsistency is that Ramadan exerts opposing influences on physical activity simultaneously. Daytime activity tends to decline as a consequence of fasting and associated fatigue, whereas evening activity tends to increase due to the social and religious practices that follow Iftar. In KSA, where daily routines change substantially during Ramadan, increased evening social and religious activity may compensate for reductions in daytime physical activity. The higher walking level observed in the KSA group lends support to this interpretation, as the post-Iftar period is typically characterized by shopping, family visits, and mosque attendance, all of which entail ambulation. Attendance at the mosque contributes to activity related to both walking and repeated standing, bowing, and prostration involved in Taraweeh prayers, which may extend over one to two hours. Given that congregational prayer is considerably more common in KSA, this practice may partially account for the observed difference in walking.

The marked sex imbalance between the two country samples should be considered when interpreting the physical activity findings. The KSA sample was predominantly male, whereas the USA sample was predominantly female, and this difference may have contributed to the higher physical activity reported in KSA. Supporting this possibility, our unpublished systematic review and meta-analysis of 14 studies, including 11 conducted in Muslim-majority countries during Ramadan and 3 conducted in non-Muslim-majority countries, found that males generally maintained their pre-Ramadan physical activity levels. In contrast, females tended to experience a reduction during Ramadan. Because the large majority of included studies were conducted in Ramadan-fasting, Muslim-majority contexts, this sex difference is likely relevant to the KSA and USA samples in the present study, although the inclusion of a small number of non-Muslim-majority studies means the pattern may not be entirely specific to Ramadan fasting. Therefore,

the observed country differences may reflect both sociocultural context and differences in sex composition rather than an independent effect of country alone. These findings should consequently be interpreted cautiously until confirmed in studies using sex-balanced samples or analyses stratified by sex.

The higher sitting time observed among USA participants is consistent with the same interpretation. In the USA, conventional occupational and commuting routines remain largely unchanged during Ramadan, and the sedentary patterns characteristic of industrialized societies are therefore maintained (Biswas et al., 2015; Katzmarzyk et al., 2009). In KSA, by contrast, working hours are formally reduced during Ramadan, which decreases occupational sitting and allows additional time for prayer and social engagement. Therefore, the higher sitting time among USA participants may reflect the continuation of usual work and commuting routines during Ramadan rather than a direct effect of fasting. However, physical activity and sitting time were assessed using the self-reported IPAQ, which may be less precise than objective monitoring. For instance, Alghamdi et al. (2020) demonstrated that wearable devices capture these behaviors with greater precision during Ramadan, and future research would therefore benefit from objective monitoring.

These findings should also be interpreted cautiously because physical activity was assessed using the IPAQ-SF, which is susceptible to recall and reporting bias and commonly overestimates activity relative to objective measures (Lee et al., 2011). Such bias may be amplified when physical activity is a study focus, as participants may report behavior in a manner consistent with perceived study expectations or social desirability (Taber et al., 2009).

Sleep

The most pronounced sleep-related difference is related to timing. KSA participants exhibited a mean bedtime approximately two and a half hours later than that of USA participants and a mean wake time approximately three hours later, with both differences representing large effect sizes. This divergence is likely attributable to differences in the temporal organization of daily life between the two settings. In KSA, Taraweeh prayers typically conclude near or after midnight, and families frequently remain awake thereafter for social visits, late meals, and the pre-dawn Suhoor. Because societal schedules shift extensively during Ramadan, individuals are able to delay sleep considerably. In the USA, by contrast, occupational and academic schedules remain largely unchanged, constraining the extent to which sleep can be delayed. These observations are in accordance with those of (Qasrawi et al., 2017), who reported that delays in bedtime and wake time emerge primarily under free-living conditions rather than under fixed schedules. The differences between the two groups provide a real-world example of how fixed and flexible schedules influence sleep timing during Ramadan.

USA participants reported shorter sleep-onset latency, with a greater proportion reporting a latency of under 15 minutes. Notably, KSA participants did not report shorter sleep duration; if anything, a slightly greater proportion reported more than seven hours of sleep, whereas USA participants were concentrated in the five-to-six-hour range. Despite this comparable or longer duration, KSA participants rated their sleep quality more poorly and reported a higher proportion of “very bad” sleep. This pattern suggests that the poorer sleep outcomes among KSA participants were related more to delayed sleep timing and reduced sleep quality than to shorter sleep duration. Longer sleep duration may not fully compensate for the adverse effects of delayed or misaligned sleep. Delayed and circadian-misaligned sleep is not functionally

equivalent to restorative sleep, even when of longer duration. These findings are consistent with the broader Ramadan sleep literature, which documents reduced sleep efficiency and increased daytime dysfunction during the month (Hsouna et al., 2019) as well as alterations in sleep architecture, including reduced REM sleep (Faris et al., 2020; Qasrawi et al., 2017). A plausible physiological contributor is suggested by Ajabnoor et al. (2014), who found that Ramadan fasting disrupted the normal diurnal cortisol rhythm in Saudi adults. Persistently elevated cortisol levels may contribute to poorer sleep quality by reducing deep sleep. This finding is particularly relevant given the demographic similarity between their sample and the present KSA group.

Anxiety and Mental Well-Being

KSA participants reported higher anxiety and lower flourishing than USA participants, with languishing more than three times as prevalent in the KSA group. This pattern is superficially counterintuitive, as the majority of prior studies report that fasting is associated with improved mental health. Yousuf et al. (2021) reported reduced anxiety following Ramadan in a Pakistani sample. In addition, Ridho and Futihandayani (2024) reported a comparable reduction in an Indonesian sample. The question therefore arises as to why the present KSA group exhibited greater, rather than lesser, anxiety and poorer mental health.

The explanation lies in the design of these prior studies, which predominantly employ within-person, pre-versus-post comparisons within a single country, thereby assessing whether fasting alters an individual's mental health. The present study addresses a distinct question: whether, with fasting held constant, mental health differs between two societies. These findings do not necessarily conflict with previous research. Instead, they highlight the role of the sociocultural context surrounding Ramadan, which within-country pre-post studies cannot examine. In a systematic review of 22 studies, concluded that the mental health effects of

Ramadan are mixed and emphasized the need to investigate how social context influences these outcomes.(Heun, 2018). Consistent with two studies conducted in Germany, Ghashang et al. (2024) and Nugraha et al. (2017) reported no significant change in anxiety during Ramadan.

Several factors may account for the poorer mental health observed in the KSA group. The pronounced delay in sleep timing and the poorer sleep quality described above are closely associated with anxiety, as circadian disruption and elevated cortisol sustain a heightened state of physiological arousal (Ajabnoor et al., 2014). The intensive social schedule characteristic of Ramadan in KSA, involving frequent gatherings and social obligations, may also contribute to strain even as it fosters social connection. Another possible reason is that when fasting represents a society-wide norm rather than an individually chosen practice, it may confer a diminished sense of autonomy, which typically enhances the psychological benefits of religious observance. Bayani et al. (2020) found that fasting supported psychological well-being, including autonomy. Moreover, Sulaiman et al. (2023) reported that perceived social relationships and physical activity, rather than intrinsic religiosity alone, predicted better mental health during Ramadan.

The comparatively favorable mental health of USA participants may reflect the positive meaning of observing Ramadan in a non-Muslim-majority society. Choosing to fasting in this context may strengthen religious identity and promote positive emotions. For instance, Jandali et al. (2024) examined a predominantly Middle Eastern Muslim population in the United States using comparable instruments and found that anxiety and depression remained within normal ranges during Ramadan despite disturbed sleep, with happiness and life satisfaction emerging as the strongest protective factors. This may explain why USA participants in the present study reported lower anxiety and higher flourishing despite fasting within a society that does not accommodate the month. Importantly, these findings should not be interpreted as indicating that

the observance of Ramadan in KSA is in any way deficient; rather, they suggest that the conditions surrounding fasting are modifiable. In a randomized controlled trial conducted in Germany, Lauche et al. (2024) found that brief pre-Ramadan lifestyle guidance improved quality of life and mindfulness. These findings suggest that interventions targeting sleep timing and daily routines may help reduce anxiety and improve flourishing among KSA participants.

Limitations

This study has several limitations. First, the cross-sectional design allowed comparisons between the two groups but did not establish whether country of residence caused the observed differences. Several of the comparison studies employed pre-versus-post designs that the present study did not (Jandali et al.; Yousuf et al., 2021). A longitudinal design following participants across Ramadan in both countries would strengthen future work. Second, all measures were self-reported, including those of sleep and physical activity, and are therefore susceptible to recall and social-desirability biases. Objective instruments such as actigraphy and accelerometry would yield more accurate data (Prince et al., 2008). Third, the two groups were not matched on key characteristics, as the KSA sample was predominantly male and the USA sample predominantly female, with additional differences in body mass index, each of which may independently influence sleep and mental health. Fourth, several potentially relevant variables were not assessed, including daytime napping, which is common in KSA and may offset delayed nocturnal sleep, the timing of meals and exercise, and individual degree of religiosity. Fifth, data from the KSA and USA samples were collected during different Ramadan years. Consequently, the observed between-country differences may have been influenced by year-specific factors, including fasting duration, weather conditions, recruitment procedures, and broader social circumstances, rather than country of residence alone. Finally, participants were self-selected and

recruited online and may therefore be more health-conscious than the general population, which may limit the generalizability of the findings.

Conclusion

This study demonstrates that the observance of Ramadan is experienced substantially differently in Saudi Arabia and the United States. KSA participants were more physically active and less sedentary but exhibited markedly later and poorer-quality sleep and reported higher anxiety and lower flourishing. USA participants were less physically active and more sedentary yet demonstrated earlier sleep timing, better subjective sleep quality, lower anxiety, and higher flourishing, notwithstanding fasting within a society that does not accommodate the month. These findings indicate that the sociocultural context in which Ramadan is observed may meaningfully influence fasting-related behavioral and psychological outcomes, an effect that single-country designs are unable to reveal. Health guidance for Ramadan should be tailored to the specific cultural setting, with particular attention to sleep timing and daily routine. Future research employing objective measures, longitudinal designs, and multinational comparisons will further clarify the relationship between this globally observed practice and health. Moreover, future research should assess cultural and contextual factors directly, including religiosity, mosque attendance, perceived social support, workplace accommodations, and family responsibilities.

5.2 Discussion Pertaining to Aim 2

The second aim of this study was to determine whether adding structured moderate-intensity aerobic exercise to Ramadan diurnal fasting produced greater improvements in body composition and resting metabolic rate than fasting alone in adults with overweight or obesity.

The main finding was that participants in the fasting-plus-exercise (RDF+EX) group experienced significant reductions in body weight, total fat mass, and visceral fat compared with those in the fasting-only (RDF) group, as indicated by significant Group $\times$ Time interactions for each of these outcomes ($p = .044$, $p = .042$, and $p = .018$, respectively). In contrast, waist circumference, body-fat percentage, and subcutaneous fat did not differ between the groups, and fat-free mass, lean mass, and resting metabolic rate were preserved in both.

Previous studies investigating Ramadan fasting and body composition have been predominantly observational, characterizing changes across the fasting period without randomization or a fasting-only comparison group. Consequently, these designs limit the extent to which observed changes can be attributed specifically to exercise. The most directly comparable randomized trial, conducted by (Maaloul et al., 2023), similarly reported greater improvements in body composition when exercise was combined with Ramadan fasting than with fasting alone. The present findings extend this limited body of evidence by demonstrating a comparable benefit of structured exercise under free-living conditions in which dietary intake was not experimentally prescribed or controlled.

The pattern of greater reductions in body weight and fat mass when structured exercise was combined with Ramadan diurnal fasting is consistent with findings from other intermittent-fasting paradigms that have incorporated exercise. Among adults with obesity, alternate-day fasting combined with endurance exercise resulted in greater reductions in body weight and more favorable changes in plasma lipid concentrations than either intervention alone (Bhutani et al., 2013). Similarly, studies combining time-restricted eating with resistance or concurrent training have reported reductions in body weight and fat mass while maintaining or increasing lean mass (Kotarsky et al., 2021; Moro et al., 2016). The findings of the present study therefore align with

the broader intermittent-fasting literature and are supported by a plausible physiological mechanism. Because energy intake decreased to a similar extent in both groups, the additional energy expenditure associated with the exercise intervention may have produced a greater cumulative energy deficit in the RDF+EX group, thereby contributing to the larger reductions in body weight and total fat mass.

The exercise dose achieved during the intervention is important for interpreting the observed findings because participants completed less than the prescribed weekly volume. The intervention included five 40-minute sessions per week, each incorporating 30 minutes of moderate-intensity aerobic exercise, for a target aerobic volume of 150 minutes per week. Participants completed 182 of the 260 prescribed sessions, corresponding to an overall attendance rate of 70.0%, approximately 3.5 sessions per week, and an average of approximately 105 minutes of aerobic exercise per week. Adherence differed across components of the exercise prescription. Among completed sessions, adherence to session duration was high, averaging 99.4% of the prescribed duration, while exercise intensity remained stable at approximately 70% of peak heart rate and averaged 100.2% of the prescribed target. In contrast, session frequency remained below the prescribed five sessions per week throughout the intervention and declined further during the final week. Thus, the lower-than-prescribed exercise dose was attributable primarily to missed sessions rather than insufficient duration or intensity during completed sessions. The emergence of favorable between-group differences in body-composition outcomes despite participants completing only approximately 70% of the prescribed aerobic volume suggests that even a moderate exercise dose may provide additional benefit when combined with Ramadan diurnal fasting. However, because the prescribed weekly frequency was not fully achieved, the findings may underestimate the effects that could occur with greater adherence. It

is therefore plausible that completion of the full prescribed exercise volume would have produced larger or more consistent changes across body-composition outcomes, although this possibility requires confirmation in studies with higher adherence and sufficient statistical power to evaluate dose–response effects.

Because dietary intake was neither prescribed nor experimentally controlled, 24-hour dietary recalls were administered before and during Ramadan to provide context for potential changes in energy intake. These data should be interpreted with caution, however, because self-reported dietary assessments are susceptible to recall bias, measurement error, and systematic underreporting, particularly in the context of an exercise intervention (Subar et al., 2003). Within these limitations, both groups reported reductions in mean daily energy intake during Ramadan, averaging approximately 643 kcal/day in the RDF group and 531 kcal/day in the RDF+EX group, with no significant between-group difference in the magnitude of change. Nevertheless, the reported reductions in energy intake appear disproportionate to the relatively modest changes in body weight observed across the intervention (Hall et al., 2011). If energy deficits of this magnitude had been accurately reported and consistently maintained throughout Ramadan, substantially greater reductions in body weight would generally have been expected. This discordance likely reflects, at least in part, the inherent limitations of self-reported dietary intake, day-to-day variation in food consumption, and possible compensatory changes in other components of energy balance. Accordingly, the dietary recall data should be regarded as descriptive evidence of reported changes in intake rather than as a precise estimate of cumulative energy deficit.

Contrary to hypothesis 2B, resting metabolic rate and resting energy expenditure remain unchanged in both groups throughout the intervention, indicating preservation rather than

suppression of resting energy expenditure. This finding is physiologically plausible because fat-free mass, a major determinant of resting metabolic rate, was maintained in both groups (Stiegler & Cunliffe, 2006). In the context of a modest, short-term negative energy balance without a significant loss of metabolically active tissue, a clinically meaningful decline in resting energy expenditure would not necessarily be expected. Consistent with the present findings, McNeil and colleagues (2014) reported no significant difference in resting metabolic rate between Ramadan and the post-Ramadan period among healthy adults. The preservation of resting metabolic rate may be clinically relevant because substantial weight loss can induce adaptive thermogenesis, a reduction in energy expenditure beyond that expected from changes in body mass and metabolically active tissue, which may promote weight regain (Stiegler & Cunliffe, 2006). In the present study, neither Ramadan diurnal fasting alone nor its combination with moderate-intensity aerobic exercise was associated with a detectable reduction in resting metabolic rate over the four-week intervention. However, given the modest magnitude of weight loss and the relatively short intervention duration, these findings should not be interpreted as definitive evidence that adaptive thermogenesis was absent, but rather that no measurable suppression of resting energy expenditure occurred under the conditions examined.

The addition of moderate-intensity aerobic exercise did not alter resting metabolic rate beyond the values observed with fasting alone, a result consistent with both the submaximal aerobic dose achieved and the preservation of fat-free mass in both groups. The one resting metabolic variable that differed between conditions was the respiratory quotient, which increased significantly within the fasting-only group but not within the fasting-plus-exercise group. Because the respiratory quotient reflects the balance of substrate oxidation, with higher values indicating greater reliance on carbohydrate and lower values indicating greater reliance on fat

(McClave et al., 2003), this rise suggests a shift toward carbohydrate oxidation at rest in the fasting-only group. This shift is most plausibly related to the altered timing of food intake that characterizes Ramadan, during which the daily eating pattern is restructured around nocturnal meals rather than distributed across the day. Such a change in meal timing can influence resting substrate utilization and may account for the greater reliance on carbohydrate oxidation observed in the fasting-only group. In the fasting-plus-exercise group, the absence of this rise is consistent with a training-related enhancement of fat oxidation, whereby the repeated aerobic stimulus may have offset the shift in substrate use associated with the altered eating pattern.

5.3 Discussion Pertaining to Aim 3

The third aim of this dissertation was to determine whether the combination of structured moderate-intensity aerobic exercise and Ramadan diurnal fasting elicited greater improvements in cardiovascular risk factors, glycemic regulation, and circulating monocyte chemoattractant protein-1 (MCP-1) than Ramadan fasting alone. Contrary to the study hypothesis, no significant Group $\times$ Time interactions were observed for any cardiometabolic or inflammatory outcome. Thus, the patterns of change over the four-week intervention did not differ significantly between groups for lipid concentrations, blood pressure, resting heart rate, indices of glycemic control, or MCP-1. Systolic blood pressure decreased significantly within the RDF+EX group but not within the RDF group; however, the absence of a significant interaction indicates that this within-group finding should not be interpreted as evidence of a differential effect of exercise. Collectively, these results suggest that adding moderate-intensity aerobic exercise to Ramadan fasting did not produce a measurable additional benefit for the assessed cardiometabolic or inflammatory outcomes over the four-week intervention period.

The reduction in systolic blood pressure observed within the RDF+EX group, from approximately 120.5 to 113.2 mmHg ($p = .046$), warrants consideration, although the absence of a significant Group $\times$ Time interaction precludes attributing this change specifically to the exercise intervention. Reductions in blood pressure have been reported during Ramadan fasting and may be mediated by changes in autonomic regulation, renal sodium handling, vascular function, and body composition (Al-Jafar et al., 2021). In the present study, the combination of aerobic exercise and the greater reduction in visceral adiposity observed in the RDF+EX group may have contributed to the decline in systolic blood pressure. However, this mechanistic interpretation remains speculative, particularly because the difference between-group was not statistically significant. The relatively small sample size and lower-than-prescribed exercise frequency may also have limited the ability to detect a differential treatment effect. Neither diastolic blood pressure nor resting heart rate changed significantly in either group, suggesting that any cardiovascular response observed during the intervention was limited primarily to systolic blood pressure. Accordingly, the within-group reduction should be interpreted as a potentially favorable finding that requires confirmation in adequately powered trials with greater adherence to the prescribed exercise dose.

Circulating lipid concentrations were largely unchanged following the intervention. No significant Group $\times$ Time interactions were observed for total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, or triglycerides, and none of these outcomes changed significantly within either group over the four weeks. These findings differ from previous reports indicating that intermittent fasting combined with endurance exercise may improve the lipid profile, particularly when the intervention produces a substantial and sustained energy deficit (Bhutani et al., 2013). Several factors may explain the absence of detectable

changes in the present study. First, baseline lipid concentrations were generally within clinically normal ranges, thereby limiting the potential magnitude of improvement and increasing the likelihood of a floor effect. Second, the four-week intervention may have been too brief for meaningful exercise-induced adaptations in lipid metabolism to become evident. Finally, participants completed approximately 70% of the prescribed exercise sessions, resulting in a lower cumulative exercise volume than intended. This reduced exposure may have attenuated the potential effect of the exercise intervention on circulating lipid concentrations.

Interpretation of the cardiometabolic and inflammatory findings may be informed by the physiological adaptations proposed to occur during fasting. Many of the metabolic effects attributed to intermittent fasting are thought to involve repeated activation of the "metabolic switch," defined as the transition from predominant reliance on hepatic glycogen and glucose toward greater mobilization and oxidation of fatty acids, accompanied by increased ketone production (Anton et al., 2018; Mattson et al., 2018). This transition generally occurs as hepatic glycogen availability declines during prolonged fasting, although its timing and magnitude vary according to baseline glycogen stores, physical activity, metabolic health, and the composition and energy content of the preceding meal. Repeated transitions between fasted, lipid-oxidative states and postprandial, glucose-dependent states have been proposed to contribute to improvements in insulin sensitivity, lipid metabolism, cellular stress resistance, and inflammatory regulation observed with some intermittent-fasting regimens (Mattson et al., 2018). Ramadan diurnal fasting differs from many experimental fasting protocols in several respects that may influence the extent and duration of this metabolic transition. The daily fasting interval is bounded by a pre-dawn meal and an evening refeeding period, during which a substantial proportion of daily energy intake may be consumed. Accordingly, although fasting

durations may be sufficient to initiate greater reliance on lipid oxidation, the extent of hepatic glycogen depletion and ketone production may vary considerably among individuals and may not be sustained for a prolonged period before the evening meal. High energy or carbohydrate intake during the nocturnal eating window may further replenish glycogen stores and shorten the duration of lipid-dominant metabolism during the subsequent fast. Thus, Ramadan fasting may induce a recurrent but relatively brief metabolic transition rather than the more prolonged metabolic switching achieved with longer fasting intervals or regimens involving greater overall energy restriction. This physiological framework may help contextualize the largely unchanged cardiometabolic and inflammatory outcomes observed in the present study. It also suggests that the metabolic response to Ramadan fasting cannot be attributed solely to the duration of daytime food abstinence but is likely shaped by the quantity, composition, and timing of food consumed during the nocturnal eating window, as well as by accompanying changes in sleep, physical activity, and circadian alignment. Nevertheless, ketone concentrations, substrate oxidation, and hepatic glycogen availability were not directly assessed in the present study; therefore, the degree to which participants engaged the metabolic switch remains uncertain and should be considered a plausible explanatory framework rather than a demonstrated mechanism.

Indices of glucose homeostasis showed no significant Group $\times$ Time interactions or within-group changes, indicating that the addition of structured exercise did not produce a detectable effect on glycemic regulation beyond Ramadan fasting alone. Nevertheless, a consistent directional pattern was observed in both groups, characterized by numerical increases in fasting glucose, fasting insulin, and the homeostatic model assessment of insulin resistance (HOMA-IR), together with a numerical decrease in the quantitative insulin sensitivity check index (QUICKI). Although none of these changes reached statistical significance, the

concordance across multiple indices may suggest a modest shift toward reduced insulin sensitivity during Ramadan. Because this pattern was observed irrespective of group assignment, it is unlikely to reflect a differential effect of the exercise intervention and may instead be related to behavioral and circadian features of Ramadan. During Ramadan, a substantial proportion of daily energy and carbohydrate intake is often consumed during the evening and pre-dawn hours, coinciding with a circadian phase in which glucose tolerance and insulin sensitivity are physiologically reduced (Morris et al., 2015; Poggiogalle et al., 2018). Ramadan-related alterations in sleep timing, reduced sleep duration, and greater sleep fragmentation may further contribute to impaired insulin sensitivity (Almeneessier & BaHammam, 2018; Qasrawi et al., 2017). These circadian and behavioral factors provide biologically plausible explanations for the observed directional pattern. However, these mechanisms were not directly evaluated in the present study, and the absence of statistically significant changes precludes the conclusion that Ramadan fasting adversely affected glycemic regulation.

The two glycation markers changed in opposite directions, a finding that should be interpreted in the context of the distinct periods of glycemic exposure represented by each measure. HbA1c decreased significantly within both groups, whereas glycated serum protein increased significantly over time in both groups. HbA1c reflects a weighted average of glycemia over approximately the preceding two to three months, with a greater contribution from more recent glucose exposure (Danese et al., 2015). Consequently, the post-Ramadan HbA1c value likely reflected glycemic exposure both before and during Ramadan. The reduction in HbA1c, therefore, cannot be attributed exclusively to the four-week intervention, particularly in the absence of non-fasting control condition. In contrast, GSP reflects glycemic exposure over a shorter period of approximately two to four weeks and was therefore more temporally aligned

with the metabolic and behavioral conditions experienced during Ramadan (Danese et al., 2015). The increase in GSP was directionally consistent with the numerical increases in fasting glucose, fasting insulin, and HOMA-IR and the corresponding decrease in QUICKI. Although these convergent patterns may indicate a modest recent increase in glycemic exposure, none of the fasting glycemic indices changed significantly, and the glycated serum protein finding should not be regarded as definitive evidence of impaired glycemic regulation. Rather, the discordant trajectories of HbA1c and glycated serum protein may reflect their different temporal sensitivities, with HbA1c integrating glycemic exposure before and during Ramadan and glycated serum protein more strongly representing the intervention period. Interpretation of glycated serum protein also requires consideration of factors unrelated to glycemia. Because the assay measures glycation of circulating serum proteins, particularly albumin, its concentration may be influenced by changes in serum protein concentration, protein turnover, hydration status, and hemoconcentration. These factors may be particularly relevant during Ramadan and could have contributed to the observed increase. Accordingly, the opposing changes in HbA1c and glycated serum protein should be interpreted cautiously and considered complementary indicators of glycemic exposure over different time intervals rather than contradictory evidence of improvement and deterioration in glycemic control.

Circulating MCP-1 concentrations increased significantly over the intervention period, as indicated by a significant main effect of time and significant within-group increases in both the RDF and RDF+EX groups. However, the absence of a significant Group $\times$ Time interaction indicates that the pattern of change did not differ between groups. Accordingly, the increase in MCP-1 cannot be attributed to the addition of exercise and instead appears to represent a response common to both Ramadan fasting conditions. This finding differs from previous reports

of reductions in selected circulating inflammatory markers during Ramadan fasting (Faris et al., 2012). Several physiological and behavioral factors may have contributed to this discrepancy. MCP-1 is a proinflammatory chemokine expressed by adipose-tissue macrophages and several other cell types and plays an important role in monocyte recruitment and adipose-tissue inflammation (Deshmane et al., 2009). Its circulating concentration may be influenced by metabolic stress and fluctuations in glucose availability. Therefore, the repeated fasting–refeeding cycles of Ramadan, the concentration of energy and carbohydrate intake during nighttime hours, and Ramadan-related alterations in sleep and circadian rhythms could plausibly have contributed to a transient increase in MCP-1. However, these mechanisms were not directly assessed in the present study and should be regarded as potential explanations rather than established causes of the observed response.

The absence of an exercise-related reduction in MCP-1 may also reflect the characteristics of the study population and intervention. Exercise-induced improvements in inflammatory profiles are generally more readily detectable among individuals with elevated baseline inflammation or substantial reductions in adiposity. The relatively low baseline MCP-1 concentrations in this metabolically healthy cohort may therefore have limited the potential for measurable improvement over the four-week intervention. In addition, the lower-than-prescribed exercise frequency and relatively modest changes in body composition may have been insufficient to elicit a detectable anti-inflammatory effect. Several methodological considerations further limit interpretation of the MCP-1 findings. Because of limited sample availability, MCP-1 was assessed at only one pre-intervention and one post-intervention time point. Moreover, assay constraints required each sample to be analyzed in a single well rather than in duplicate. Given the biological variability of circulating inflammatory biomarkers, a single measurement

may not adequately represent an individual's usual MCP-1 concentration. The observed increase in MCP-1 should therefore be interpreted cautiously.

Collectively, the findings from Aim 3 indicate that the combination of structured moderate-intensity aerobic exercise and Ramadan diurnal fasting did not elicit detectable additional adaptations in cardiovascular function, glycemic regulation, or systemic inflammation over the four-week intervention. The observed responses, including the within-group reduction in systolic blood pressure, the discordant changes in HbA1c and glycated serum protein, and the increase in circulating MCP-1, either occurred in the absence of a significant Group $\times$ Time interaction or were common to both intervention groups. Accordingly, these changes cannot be attributed specifically to the exercise intervention.

Several factors may have limited the magnitude of adaptation. Participants were metabolically healthy and generally presented with cardiometabolic values within normal clinical ranges at baseline, thereby reducing the available scope for improvement and potentially limiting detectable change. In addition, the intervention lasted only four weeks, and the exercise frequency achieved was approximately 70% of that prescribed because of missed sessions. The resulting training dose may therefore have fallen below the threshold required to produce consistent systemic cardiometabolic adaptations, despite adequate intensity and duration during complete sessions. The metabolic and circadian characteristics of Ramadan, including repeated fasting–refeeding cycles, nocturnal energy intake, and changes in sleep timing, may also have modified the physiological response to exercise.

Strengths and Limitations

A major strength of this study is its randomized controlled design. To our knowledge, this study is among the first studies to examine the addition of structured exercise to Ramadan fasting

without prescribing dietary changes. This approach improves ecological validity and distinguishes the study from previous combined interventions that also produced substantial caloric restriction. The use of dual-energy X-ray absorptiometry provided objective and reliable assessment of total and regional body composition, including fat mass, fat-free mass, lean mass, and percent body fat. Finally, exercise adherence was objectively monitored across frequency, duration, and intensity, and dietary intake was characterized before and during Ramadan, allowing us to show that the two groups did not differ substantially in energy or macronutrient intake. Finally,

Several limitations should be acknowledged. The sample size was small, which limited statistical power and most likely explains why several clinically relevant differences—in body weight, total fat mass, and systolic blood pressure favored the exercise group but did not reach significance. The intervention was confined to the four weeks of Ramadan, so the durability of the observed changes could not be assessed. The cohort was metabolically healthy, which restricts generalizability to individuals with established cardiometabolic impairment and constrains the extent to which glycemic and lipid outcomes could improve. The prescribed exercise was moderate-intensity aerobic training only; a more vigorous or concurrent intervention, as used elsewhere, might have elicited broader cardiometabolic effects. MCP-1 was quantified from a single measurement due to limited sample volume, which may have increased measurement variability. In addition, visceral fat was estimated using dual-energy X-ray absorptiometry rather than directly quantified with computed tomography or magnetic resonance imaging; therefore, the visceral fat findings should be interpreted cautiously. Finally, although dietary intake was monitored, it was not controlled, so residual differences in intake cannot be entirely excluded.

Future Research Recommendations

Future studies should recruit larger samples with a priori power estimation anchored to the visceral-fat effect observed here, so that the promising trends for body weight, fat mass, and systolic blood pressure can be tested definitively. Given that the magnitude of the energy deficit and the exercise modality appear to shape the response, trials that systematically compare moderate aerobic training with higher-intensity or concurrent intervention, and that document intake without necessarily controlling it, would help isolate the contribution of each component. Extending measurement beyond Ramadan would establish whether the reductions in visceral fat and the within-group changes in blood pressure and glycation markers persist or reverse once habitual eating resumes. Future studies should apply this design to populations with cardiometabolic impairments, who may have greater potential for improvement than individuals with near-normal baseline values. They should also include a broader panel of inflammatory markers and replicate measurements to better characterize changes in MCP-1. Finally, because session frequency was the dimension in which adherence fell short, strategies to support consistent attendance deserve attention.

Conclusion

Among adults with overweight or obesity who observed Ramadan fasting, adding moderate-intensity aerobic exercise resulted in a greater reduction in visceral fat than fasting alone. The exercise group also showed nonsignificant trends toward greater reductions in body weight, total fat mass, and systolic blood pressure. Fat-free mass and resting metabolic rate were preserved in both groups, indicating that the combined intervention and Ramadan fasting did not compromise lean tissue or suppress resting energy expenditure. The present study did not control dietary intake and used a moderate-intensity aerobic exercise intervention. Under these

conditions, glycemic, lipid, and inflammatory outcomes did not differ between groups, possibly because participants were metabolically healthy and the intervention was relatively brief and modest in intensity. Taken together, these results support the addition of moderate aerobic exercise as a safe and practical strategy to enhance the reduction of central adiposity during Ramadan, while underscoring that eating behavior during the nocturnal window remains an important determinant of overall metabolic benefit.

Appendices

- A. International Physical Activity Questionnaire (IPAQ-SF)
- B. Pittsburgh Sleep Quality Index (PSQI)
- C. Generalized Anxiety Disorder 7-item (GAD-7)
- D. Mental Health Continuum-Short Form (MHC-SF)
- E. Study Flyer
- F. Screening questionnaire
- G. Email script
- H. Phone call script
- I. Informed consent
- J. CONSORT Flow Diagram
- K. Exercise instruction
- L. Activity monitoring instructions
- M. Individual paired data

Appendix A. International Physical Activity Questionnaire (IPAQ-SF)

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

_____ **days per week**

☐

No vigorous physical activities



Skip to question 3

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐

Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

☐

No moderate physical activities



Skip to question 5

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐

Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐

No walking



Skip to question 7

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐

Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐

Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

Appendix B. Pittsburgh Sleep Quality Index (PSQI)

Instructions: The following questions relate to your usual sleep habits during the past month only. Your answers indicate the most accurate reply for the majority of days and nights in the past month. Please answer all the questions.

During the past month,

1. When have you usually gone to bed? _____
2. How long (in minutes) has it taken you to fall asleep each night? _____
3. When have you usually gotten up in the morning? _____
4. How many hours of actual sleep do you get at night? (This may be different than the numbers of hours you spend in bed) _____

5. During the past month, how often have you had trouble sleeping because you...	Not during the past month (0)	Less than once a week (1)	Once or twice a week (2)	Three or more times a week (3)
a. Cannot get to sleep within 30 minutes				
b. Wake up in the middle of the night or early morning				
c. Have to get up to use the bathroom				
d. Cannot breathe comfortably				
e. Cough or snore loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				
j. Other reason(s), please describe, including how often you have had trouble sleeping because of this reason(s):				
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?				
	Very good (0)	Fairly good (1)	Fairly bad (2)	Very bad (3)
9. During the past month, how would you rate your sleep quality overall?				

Component 1 #9 Score C1 _____
 Component 2 #2 Score (≤ 15 min=0; 16-30 min=1; 31-60 min=2; >60 min=3) + #5a Score
 (if sum is equal 0=0; 1-2=1; 3-4=2; 5-6=3) C2 _____
 Component 3 #4 Score ($> 7=0$; 6-7=1; 5-6=2; $< 5=3$) C3 _____
 Component 4 (total # of hours asleep)/(total # of hours in bed) x 100
 >85%=0, 75%-84%=1, 65%-74%=2, <65%=3 C4 _____
 Component 5 Sum of scores #5b to #5j (0=0; 1-9=1; 10-18=2; 19-27=3) C5 _____
 Component 6 #6 Score C6 _____
 Component 7 #7 Score + #8 Score (0=0; 1-2=1; 3-4=2; 5-6=3) C7 _____
 Add the seven component scores together _____ **Global PSQI Score** _____

Appendix C. Generalized Anxiety Disorder 7-item (GAD-7)

Over the Last 2 weeks, how often have you been bothered by any of the following problems?	NOT AT ALL	SEVERAL DAYS	MORE THAN HALF THE DAYS	NEARLY EVERY DAY
1. Feeling nervous, anxious or on edge	☐ ☐	☐ ☐	☐ ☐	☐ ☐
2. Not being able to stop or control worrying	☐ ☐	☐ ☐	☐ ☐	☐ ☐
3. Worrying too much about different things	☐ ☐	☐ ☐	☐ ☐	☐ ☐
4. Trouble relaxing	☐ ☐	☐ ☐	☐ ☐	☐ ☐
5. Being so restless that it is hard to sit still	☐ ☐	☐ ☐	☐ ☐	☐ ☐
6. Becoming easily annoyed or irritable	☐ ☐	☐ ☐	☐ ☐	☐ ☐
7. Feeling afraid as if something awful might happen	☐ ☐	☐ ☐	☐ ☐	☐ ☐

8. If you checked off any problems on this questionnaire so far, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?			
Not difficult at all	Somewhat difficult	Very difficult	Extremely difficult
☐ ☐	☐ ☐	☐ ☐	☐ ☐

Appendix D. Mental Health Continuum-Short Form (MHC-SF)

Adult MHC-SF (ages 18 or older)

Please answer the following questions are about how you have been feeling during the past month. Place a check mark in the box that best represents how often you have experienced or felt the following:

During the past month, how often did you feel ...	NEVER	ONCE OR TWICE	ABOUT ONCE A WEEK	ABOUT 2 OR 3 TIMES A WEEK	ALMOST EVERY DAY	EVERY DAY
1. happy						
2. interested in life						
3. satisfied with life						
4. that you had something important to contribute to society						
5. that you belonged to a community (like a social group, or your neighborhood)						
SEE BELOW 6. that our society is a good place, or is becoming a better place, for all people						
7. that people are basically good						
8. that the way our society works makes sense to you						
9. that you liked most parts of your personality						
10. good at managing the responsibilities of your daily life						
11. that you had warm and trusting relationships with others						
12. that you had experiences that challenged you to grow and become a better person						
13. confident to think or express your own ideas and opinions						
14. that your life has a sense of direction or meaning to it						

Note: The original wording for item 6 was “that our society is becoming a better place for people like you.” This item does not work in all cultural contexts. However, when validating the MHC-SF, test both versions of item 6 to see which one works best in your context.

Adolescent MHC-SF (ages 12 to 18)

Please answer the following questions are about how you have been feeling during the past month. Place a check mark in the box that best represents how often you have experienced or felt the following:

During the past month, how often did you feel ...	NEVER	ONCE OR TWICE	ABOUT ONCE A WEEK	2 OR 3 TIMES A WEEK	ALMOST EVERY DAY	EVERY DAY
1. happy						
2. interested in life						
3. satisfied with life						
4. that you had something important to contribute to society						
5. that you belonged to a community (like a social group, your school, or your neighborhood)						
SEE BELOW 6. that our society is a good place, or is becoming a better place, for all people						
7. that people are basically good						
8. that the way our society works made sense to you						
9. that you liked most parts of your personality						
10. good at managing the responsibilities of your daily life						
11. that you had warm and trusting relationships with others						
12. that you had experiences that challenged you to grow and become a better person						
13. confident to think or express your own ideas and opinions						
14. that your life has a sense of direction or meaning to it						

Note: The original wording for item 6 was “that our society is becoming a better place for people like you.” This item does not work in all cultural contexts. However, when validating the MHC-SF, test both versions of item 6 to see which one works best in your context.

Appendix E. Study Flyer



**SCHOOL OF KINESIOLOGY
PHYSICAL ACTIVITY &
HEALTH LABORATORY**
UNIVERSITY OF MICHIGAN

Call for participants to take part in a research study during Ramadan

IRB: HUM00247761

ABOUT THE STUDY

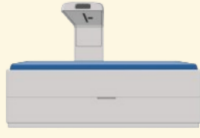
The study aims to investigate how Ramadan fasting, combined with a structured aerobic exercise program, can be beneficial for improving body composition, cardiometabolic health, and overall well-being in adults with obesity

WHAT IS INVOLVED

You will be asked to visit the SOK Clinical Lab once before Ramadan and once during the last week of Ramadan. Each visit will take approximately 90 minutes. Each clinical visit will include the following tests:



VO₂ max



Body composition



Metabolic health



Energy expenditure

WHO CAN PARTICIPATE

- 22-60 years old
- Adults with obesity (BMI ≥ 30 kg/m²)
- In good health, without chronic conditions
- Not taking medications that could affect participation
- Weight stable (no gain or loss greater than 6 pounds in the past 2 months)
- Planning to fast the entire month
- Not exercising regularly (< 2 times per week)

BENEFITS

- Receive information on your health markers (BMI, blood pressure, fasting glucose)
- Results from this study may help inform future health recommendations
- A \$100 gift card as a thank-you after completing study requirements

For inquiries:

Abdullah Alwaleedi
Email: waleedi@umich.edu
Phone number: 734-882-9518

Scan the QR code to assess your eligibility





Figure 3. Study Flyer

Appendix F. Screening Questionnaire

Start of Block: Default Question Block

Full Name

Phone number

Email address

Age

Gender

- ☐ Male
- ☐ Female

How did you first hear about our study?

- ☐ UMhealthresearch.org
- ☐ Flyer (Please tell us where you found the flyer, e.g. WhatsApp)
-
- ☐ Social media (i.e. Facebook, Instagram, etc)
- ☐ Direct email from study team
- ☐ Other (Please indicate how)
-

Height (include unit, e.g. feet, centimeter)

Weight (include unit, e.g. kg, pound)

Have you ever been diagnosed with a cardiovascular or metabolic disease?

☐ Yes

☐ No

☐ Other (Please specify) _____

Are you a smoker (e.g. use of cigarettes, vaping, Hookah)?

☐ Yes

☐ No

Are you taking any medicines that affect your metabolism or inflammation?

☐ Yes

☐ No

☐ Other (Please specify)

End of Block: Default Question Block

Appendix G. Email Script

Hello,

This is Abdullah Alwaleedi, a Ph.D. student in the school of kinesiology at the University of Michigan. I am excited to invite you to participate in a research study conducted at the University of Michigan exploring the effects of Ramadan fasting on cardiometabolic health.

If you are:

- An adult male who observes Ramadan fasting, and
- Be healthy and free of cardiovascular and metabolic diseases
- Be sedentary overweight and obese (BMI 27-40)
- Nonsmoker
- Not taking any medications affecting your metabolism and inflammation

What Does Participation Involve?

- Attending two clinical visits: one before Ramadan and one during the last week of Ramadan.
- Wearing an actigraph for seven consecutive days to monitor your sleep and physical activity.
- If assigned to the exercise group, participating in moderate-intensity aerobic training either in a clinical lab in the School of Kinesiology or virtually .

Benefits of Participation:

You'll gain insights into your health, including weight, body composition, and cardiometabolic markers. Alsoy

How to Get Started:

To determine your eligibility, please complete a short screening questionnaire using the link or barcode attached:

https://umich.qualtrics.com/jfe/form/SV_ddwkd189rq2t0hw

If you have any questions or need more information, feel free to reply to this email or contact us at (734) 882-9518 or waleedi@umich.edu

Warm regards,

Abdullah Alwaleedi

Ph.D. student

School of Kinesiology – University of Michigan

Appendix H. Phone Call Script

Start the call

Hello, my name is Abdullah Alwaleedi, and I'm a Ph.D. student in the School of Kinesiology at the University of Michigan. Thank you for expressing interest in our study about the effects of Ramadan fasting on metabolic health outcomes. May I confirm that this is a good time to speak with you for a few minutes about the study?"

[Wait for confirmation. If no, ask for a better time to call back.]

Purpose of the Study

"Our study is focused on understanding how Ramadan fasting, combined with or without moderate-intensity aerobic exercise, impacts weight loss and cardiometabolic health. The study involves participation both before and during Ramadan."

Eligibility Screening

To determine if you are eligible to participate, I'd like to confirm a few details about your general health, fasting habits, and exercise routine.

The eligibility criteria for this study are as follows:

- Participants must be sedentary males aged 18–65 years.
- Participants must have a BMI between 30–40 kg/m².
- Participants must be fasting the entire month of Ramadan.

You would not be eligible if:

- You fast only part of Ramadan.
- You currently participate in regular exercise.
- You are a smoker.
- You have a history of cardiovascular or metabolic diseases
- You are taking medications that affect metabolism or inflammation.

May I confirm your eligibility based on these criteria?

[If yes, continue to study procedures. If no, thank the individual and end the call.]

Study Procedures

"If you are eligible and decide to participate, here's what the study would involve:

1. Assessments will take place twice: once before Ramadan and once during Ramadan. These assessments include measuring your body composition, resting energy expenditure, aerobic capacity and certain blood markers.
2. You will be asked to wear an actigraph for seven consecutive days to monitor your sleep and physical activity.
3. If you are in the exercise group, you will participate in moderate-intensity aerobic training, which can be done in a school of kinesiology (fitness center) or virtually with a Polar heart rate monitor to track your exercise intensity.
4. Blood samples will be collected during each assessment.
5. I will provide detailed instructions for each part of the study to ensure your safety and comfort."

Benefits and Risks

Participation in the study may help you learn more about your health, including weight, body composition, and cardiometabolic markers. However, there are some minor risks, such as mild discomfort from blood draws or fatigue from exercise, which we will work together to minimize with proper procedures.

Confidentiality

I'd also like to assure you that all your personal information will be kept confidential. Data will be anonymized, and only me as the student investigator and the study team will have access to it.

Participation Details

Participation is voluntary, and you can withdraw at any time. If you decide to join, I will provide detailed schedules and instructions. Would you like to receive additional information via email or discuss any questions you have about the study?

[Answer any questions and provide contact information for follow-up.]

Closing

Thank you so much for your time. If you're interested in participating, I'll send you the next steps and consent form via email or text. Please don't hesitate to reach out if you have any further questions. Have a wonderful day!

Appendix I. Informed Consent

UNIVERSITY OF MICHIGAN CONSENT TO BE PART OF A RESEARCH STUDY

1. KEY INFORMATION ABOUT THE RESEARCHERS AND THIS STUDY

Study title: Effects of Ramadan diurnal intermittent fasting combined with moderate-intensity continuous training on cardiometabolic health in subjects with overweight and obesity

Principal Investigator: Abdullah Alwaleedi, M.ED , University of Michigan

Faculty Advisor: Weiyun Chen, Ph.D., University of Michigan

You are invited to take part in a research study. This form contains information that will help you decide whether to join the study.

Taking part in this research project is voluntary. You do not have to participate, and you can stop at any time. Please take time to read this entire form and ask questions before deciding whether to take part in this research project.

2. PURPOSE OF THIS STUDY

Aerobic exercise has many positive health benefits and we believe some of these effects of aerobic exercise improve health when it is performed during fasting. Therefore, this study is being done to examine the effects of aerobic exercise combined with Ramadan fasting on cardiometabolic health.

3. WHO CAN PARTICIPATE IN THE STUDY

Taking part in this study is completely **voluntary**. You do not have to participate if you don't want to. You may also leave the study at any time. If you leave the study before it is finished, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled.

3.1 Who can take part in this study?

This study includes only men between the ages of 18-65 years old with overweight or obesity (BMI 27-40 kg/m²). In addition, participants should be stable weight stable (± 2 kg for over two months) and sedentary (<30 min of exercise, 3 times per week) and intend to fast the whole month of Ramadan.

Exclusion criteria for this study include being female, fasting only part of Ramadan, currently participating in regular exercise, current tobacco use, a history of cardiovascular or other metabolic diseases (including cancer), and taking medications that affect metabolism or inflammation.

3.2 How many people are expected to take part in this study?

Approximately 30 subjects with overweight and obesity are expected to complete this study.

4. INFORMATION ABOUT STUDY PARTICIPATION

4.1 What will happen to me in this study?

This is a four-week aerobic exercise training study conducted during the month of Ramadan. Participation in this study requires a baseline visit (before Ramadan) and then be randomly assigned to an aerobic exercise combined with a Ramadan fasting group (RDIF-EX) or a Ramadan fasting-only group (RDIF).

Before Ramadan begins, you will complete a baseline visit at the Kinesiology Building's Clinical Research Suite (CRS) located on the University of Michigan's Central Campus and will take about 90 minutes to complete, where several testing procedures will be done. Soon after this visit is completed, you will be assigned to either the Ramadan and exercise group (RDIF-EX) or the Ramadan fasting-only group (RDIF).

Whether you are assigned to (RDIF-EX) or (RDIF), you will undergo a second visit during the first week following the month of Ramadan at the (CRS) where you will complete the same

testing procedures as you did before Ramadan (Baseline visit), except for graded exercise test ($\text{VO}_{2\text{max}}$).

Baseline Clinical visit

The baseline clinical visit will take approximately 90 minutes to complete and will include final eligibility assessments to confirm your participation in the study. While preliminary eligibility will be determined through the screening questionnaire, full eligibility will be established during the first portion of the baseline visit. This will include verifying your height and weight using calibrated equipment to calculate BMI. These assessments will ensure that you meet all the inclusion criteria for the study.

For the baseline visit, you will be asked to arrive at the Clinical Exercise Research Center (CERC) in the morning following an overnight fast for 10–12 hours, with no food or drink except water. Parking space will be provided upon request. Upon arrival, the student investigator will review the informed consent document with you in detail, ensuring that you fully understand the study procedures, risks, and benefits. You will have the opportunity to ask any questions you may have. After the informed consent form has been thoroughly reviewed, discussed, and signed, confirming your understanding and agreement to participate in the study, the student investigator will proceed with some basic assessments to finalize eligibility and collect baseline data (SEE BELOW):

- **Resting metabolic rate (RMR) test:** the resting metabolic rate (RMR) test is used as a diagnostic tool to evaluate your body's energy expenditure at rest, which is an essential factor in understanding your overall metabolic health and readiness to participate in the study. This test will help determine how many calories your body burns while at rest. During the test, you will be asked to rest quietly while wearing a mask that covers your nose and mouth. This mask will capture and analyze the air you breathe out, allowing the student investigator to measure your resting metabolic rate accurately.
- **Body composition:** the body composition assessment using Dual-Energy X-ray Absorptiometry (DEXA) involves a straightforward and non-invasive procedure where you will lie flat on a cushioned table while the scanning arm moves slowly across your body. This scanning arm emits low-dose X-rays that pass through your body to measure bone density, fat mass, and lean muscle mass. The process is painless and requires you to remain still for a few minutes while the scan is conducted.

Blood Drawing: the blood draw procedure is a standard part of the study to collect important information about your health. During this procedure, the student investigator, who is trained and certified, will gently insert a small needle into a vein in your arm to draw approximately two tubes of blood, totaling about 15 mL. The process is typically quick and involves minimal discomfort. The collected blood sample will be used to analyze various biomarkers essential for understanding your health and how your body responds to Ramadan fasting with or without exercise.

- **Graded exercise testing (GXT):** this test is used as a diagnostic evaluation to ensure you are in a good health and capable of completing the study procedures and exercise training. Additionally, this exercise stress test will provide insight into your exercise capacity (i.e., physical fitness). This test is a supervised treadmill test. You will still be equipped with a mouthpiece and a clip will be placed over your nose so that all the air you breathe in and out, will pass through the mouthpiece and into a machine alongside the treadmill. During this test, your heart rate, and feelings of how hard you are working will also be monitored. You will walk or jog on a treadmill, with the incline progressively increased every few minutes, until fatigue, breathlessness, and/or symptoms indicate to the student investigator or yourself, that you should stop the exercise. The entire GXT procedure, including setup, is expected to take approximately 15-20 minutes.
- **Physical activity and sleep monitoring:** As part of this study, you will be asked to wear an actigraphy device, which is a small, wrist-worn monitor that tracks your physical activity and sleep patterns. The purpose of this device is to help us understand your daily activity levels during Ramadan. You will need to wear the device on your non-dominant wrist for seven consecutive days before and during Ramadan, including during sleep, bathing, and exercise, as it is waterproof and can be worn 24/7. The device automatically records your movement, so you don't need to do anything manually. It's important that you wear the device consistently throughout the assigned seven days to ensure accurate data collection. If you need to remove it for any reason, please make a note of the time and reason in the log provided. The device will also monitor your sleep, so please keep it on overnight. At the end of each clinical visit, we will provide instructions for returning the device.
- **Dietary intake monitoring:** As part of the study, you will be asked to track your dietary intake and eating patterns for three days before Ramadan and three days during Ramadan using the MyFitnessPal app. This app is easy to use and allows you to log your meals, snacks, and beverages in real time, providing us with valuable insights into your eating behaviors. Instructions on how to use the app will be provided during the baseline visit to ensure you are comfortable with the process
- **Questionnaire:** You will be asked to complete two questionnaires.
 - **DASS-21 (Depression, Anxiety, and Stress Scales-21):** is a brief 21-item self-report questionnaire designed to measure the emotional states of depression, anxiety, and stress.
 - **Physical Activity Enjoyment Scale:** which will assess your level of enjoyment during physical activity

Second visit (Ramadan)

This visit will take place during the first week following the month of Ramadan and will include the metabolic and behavioral assessments, including Resting metabolic rate (RMR) test, Body

composition, Blood drawing, and Physical activity and sleep monitoring. Details about these measurements are **previously described**.

Exercise training (RDIF-EX):

If you are assigned to the experimental group, you will participate in a supervised aerobic exercise program during Ramadan. The exercise sessions will last 40 minutes each and will occur five times per week. Each session will include:

1. **Warm-Up:** A 5-minute dynamic stretching routine to prepare your body for aerobic activity.
2. **Aerobic Activity:** 30 minutes of continuous moderate-intensity exercise performed at 65–75% of your heart rate peak (calculated during the baseline visit using the VO₂ max test). Moderate intensity means exercising at a level where you can still speak in short sentences but cannot carry on a full conversation comfortably. To help you maintain the prescribed intensity, you will wear a Polar heart rate monitor during each session. This monitor will display your heart rate in real time to allow you to adjust your effort to stay within the target range. For example, you can increase or decrease your walking or cycling speed or adjust resistance levels if using equipment.
3. **Cool-Down:** A 5-minute routine consisting of slow walking and dynamic stretching to safely lower your heart rate and relax your muscles.

If you choose to exercise in the kinesiology gym, the student investigator will supervise your sessions in real-time, monitor your heart rate, and provide feedback to help you stay within the target intensity range. If you choose to participate virtually, you will receive detailed instructions covering the exercise program, managing exercise intensity, using the Polar heart rate monitor to track your intensity, dehydration prevention tips, and safety recommendations. The student investigator will remotely monitor your heart rate data and follow up with you as needed.

All exercise sessions will take place approximately one hour before sunset, in alignment with Ramadan fasting practices. Please note that you may stop or modify the exercise session at any time if you feel discomfort or fatigue.

Control group (RDIF only):

If you are assigned to the control group, you will participate in Ramadan fasting without an exercise intervention. Your involvement will include completing the aforementioned two assessments: one before Ramadan and one during the first week following Ramadan. While there are no additional activities required beyond fasting, your participation will help us understand the effects of Ramadan fasting alone on health outcomes.

4.2 How much of my time will be needed to take part in this study?

Your participation in this study will last approximately six weeks. A total of two visit will be included in this study. The baseline visit (before Ramadan) will last about 90 minutes and will take place during the month preceding Ramadan. The second visit (post Ramadan visit) will last approximately 60 minutes and will take place during the week following the month of Ramadan.

5. INFORMATION ABOUT STUDY RISKS AND BENEFITS

5.1 What risks will I face by taking part in the study? What will the researchers do to protect me against these risks?

The known or expected risks are:

1. Risk of Dehydration or Fatigue Due to Fasting and Exercise (RDIF-EX Group Only):

Fasting combined with exercise during Ramadan may increase the risk of dehydration or fatigue since participants cannot consume food or water during daylight hours.

Likelihood: Likely (10-25%)

Seriousness: Moderate to serious

Measures to Minimize Risk:

1. You will be encouraged to stay hydrated during non-fasting periods (after sunset and before dawn).
2. Exercise sessions will take place one hour before breaking the fast (sunset) and will be closely monitored to allow breaks and adjustments if needed.

2. Risk of Heat Illness Due to Fasting and Exercise (RDIF-EX Group Only): Fasting combined with exercise during Ramadan may increase the risk of heat illness, including overheating, dizziness, or heat exhaustion, due to limited fluid intake and physical activity.

Likelihood: Likely (10-25%)

Seriousness: Moderate to serious

Measures to Minimize Risk:

1. You will be advised to exercise in a well-ventilated or air-conditioned space and follow safety guidelines provided in the handout.
2. You will be encouraged to stop exercising immediately if you experience symptoms such as dizziness, nausea, extreme fatigue, or any other signs of heat illness. If symptoms persist, you should seek medical attention promptly.

3. Musculoskeletal Injury During Exercise (RDIF-EX group only)

Likelihood: Rare (<1%)

Seriousness: Mild to moderate. While the risk of musculoskeletal injury is inherent in any physical exercise, it is rare, especially under supervision and with proper precautions.

Measures to Minimize Risk:

1. Exercise sessions in the SOK will be supervised by the student investigator to ensure proper form and to adjust intensity as needed. Participants engaging virtually will receive a handout with tips for exercising safely and effectively. They will also be encouraged to contact the student investigator during their exercise sessions report any discomfort or issues immediately
2. A thorough warm-up (5 mins) and cool-down (5 mins) will be performed to reduce the likelihood of injury.

4. **Risk of Complications from Blood Draw (All Participants):** blood draws may cause mild discomfort, bruising, or very rarely, an infection.

Likelihood: Rare (<1%)

Seriousness: Mild

Measures to Minimize Risk:

1. Blood draws will be performed by trained personnel using sterile techniques to minimize risks.

5. Exposure to DEXA Radiation (RDIF & RDIF-EX Groups)

Likelihood: Rare (<1%)

Seriousness: Mild. The DEXA scan involves low levels of radiation exposure, which are well within safe limits and comparable to the amount of radiation from a cross-country flight.

Measures to Minimize Risk:

1. The DEXA scan will be conducted by the student investigator, who has completed safety training provided by the university, and will follow all established safety protocols.
2. Participants will be informed about the safety of DEXA and the low risk associated with its use.

6. **Risk of Breach of Confidentiality (All Participants):** there is a small chance of your personal or health-related information being exposed.

Likelihood: Rare (<1%)

Seriousness: Moderate

Measures to Minimize Risk:

1. All data will be stored on secure, password-protected servers.
2. Physical documents will be kept in locked cabinets within a secure location.
3. Participants will be assigned unique ID numbers to anonymize their data.
4. Access to the data will be restricted to the student investigator and study team.

5.2 How could I benefit if I take part in this study? How could others benefit?

You might benefit from being in the study by improving your health and fitness if you are assigned to the exercise group. Additionally, you will obtain values for testing results, such as body composition and metabolic health which may provide useful insights into your current health status.

5.3 Will the researchers tell me if they learn of new information that could change my willingness to stay in this study?

Yes, the researchers will tell you if they learn of important new information that may change your willingness to stay in this study. If new information is provided to you after you have joined the study, it is possible that you may be asked to sign a new consent form that includes the new information.

6. ENDING THE STUDY

6.1 If I want to stop participating in the study, what should I do?

You are free to leave the study at any time. If you leave the study before it is finished, there will be no penalty to you. If you decide to leave the study before it is finished, please tell one of the persons listed in Section 9. “Contact Information”. If you choose to tell the researchers why you are leaving the study, your reasons may be kept as part of the study record. The researchers will keep the information collected about you for the research unless you ask us to delete it from our records. If the researchers have already used your information in a research analysis it will not be possible to remove your information.

7. FINANCIAL INFORMATION

7.1 Will I be paid or given anything for taking part in this study?

You will receive \$100 as compensation for your participation in the study. Payment will be provided after you have completed both the baseline and post Ramadan visits and returned the activity monitors provided for the study. Please note that compensation will not be provided if you withdraw from the study before completing both visits or fail to return the activity monitors.

If you receive any payments for taking part in this study, the University of Michigan finance department will need your name and address for tax reporting purposes. In a calendar year if: 1) your payments total greater than \$400 for this study or 2) if you receive payments of greater than \$400 for being in more than one study, the University of Michigan finance department will also require your Social Security Number for tax reporting purposes. If you do not wish to provide your Social Security Number, you may continue to participate in research studies, but you will not be able to receive payment for the remainder of the calendar year.

7.2 Who could profit or financially benefit from the study results?

No person or organization has a financial interest in the outcome of this study.

8. PROTECTING AND SHARING RESEARCH INFORMATION

8.1 How will the researchers protect my information?

To protect your confidentiality, your data will be stored using unique participant ID, which will be kept separate from any identifying information, such as informed consent form or screening questionnaire. Data collected may be used for a scientific purpose with your confidentiality maintained. Data in paper format will be securely stored in a locked suite within the field-based research center. Electronic data will be stored on an encrypted university-issued laptop. The data collected for this study will be used solely for the purposes outlined in the current study protocol. There are no plans to share or reuse the data for any future research. All data will remain confidential and will not be shared beyond the scope of this study.

Paper records will be securely stored in a locked suite, and electronic data will be stored on an encrypted university-issued laptop. All data will be destroyed a year after the completion of the study's analysis and reporting phase.

8.2 Who will have access to my research records?

8.3

There are reasons why information about you may be used or seen by the researchers or others during or after this study. An example is the Institutional Review Board (IRB) may need the information to make sure that the study is done in a safe and proper manner.

9. CONTACT INFORMATION

Who can I contact about this study?

Please contact the researchers listed below to:

- Obtain more information about the study
- Ask a question about the study procedures
- Report an illness, injury, or other problem (you may also need to tell your regular doctors)
- Leave the study before it is finished
- Express a concern about the study

Student Investigator: Abdullah Alwaleedi

Email: waleedi@umich.edu

Phone: (734)-882-9518

Faculty Advisor: Dr. Weiyun Chen

Email: chenwy@umich.edu

Phone: (734)-615-0376

If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the following:

University of Michigan

Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS)

2800 Plymouth Road

Building 520, Room 2144

Ann Arbor, MI 48109-2800

Telephone: 734-936-0933 or toll free (866) 936-0933

Fax: 734-936-1852

E-mail: IRBHSBS@UMICH.EDU

You can also contact the University of Michigan Compliance Hotline at 1-866-990-0111.

10. YOUR CONSENT

Consent to Participate in the Research Study

By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. I will give you a copy of this document for your records and I will keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information in Section 9 provided above.

I understand what the study is about and my questions so far have been answered. I agree to take part in this study.

Print Legal Name: _____

Signature: _____

Date of Signature (mm/dd/yy): _____

Appendix J. CONSORT Flow Diagram

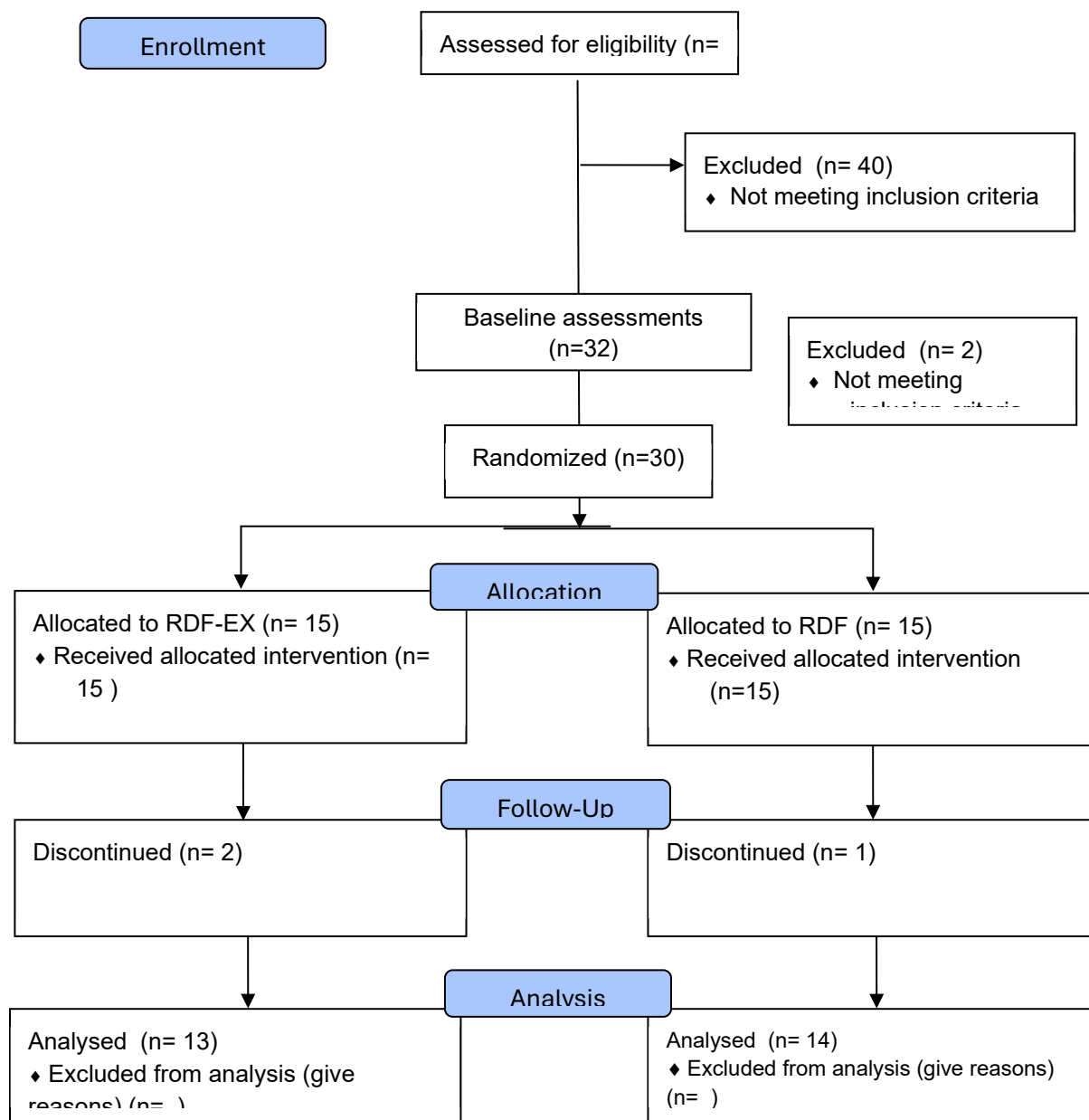


Figure 4. CONSORT Flow Diagram

Appendix K. ACSM Guidelines for Aerobic Exercise Intensity

Table 12. ACSM Guidelines for Aerobic Exercise Intensity

Intensity Level	HRR (%)	HRmax (%)	VO₂max (%)	METs	Other Indicators / Examples
Light / Low	~30-39 %	~57-63 %	~20-39 %	<3	Easy pace; minimal shortness of breath; can sing comfortably.
Moderate	~40-59 %	~64-76 %	~40-59 %	3-5.9	Walk briskly; conversation possible but with effort; somewhat hard; steady breathing.
Vigorous	~60-89 %	~77-95 %	~60-89 %	≥6	Running, race pace, steep hill climbs; talking is difficult except in short bursts; heavy breathing.

Appendix L. Exercise Instructions

EXERCISE COMPONENTS

DURATION

- 5 days a week
- 40 mins each session

Intensity level

65-75% of your max heart rate, monitored via chest strap

Exercise Mode

Aerobic activity (walk, jog, cycle, elliptical)
Choose what works for you!

RAMADAN STUDY

EXERCISE & SAFETY GUIDELINES DURING RAMADAN

This sheet provides important instructions and safety tips to help guide your exercise sessions throughout the study, whether you're exercising in person or remotely. Please read it carefully to get the most out of your participation!

HOW TO START

PRE-EXERCISE INSTRUCTIONS

HR MONITOR SET-UP

Wear the heart rate monitor snugly around your chest before exercising. Ensure the sensor is in direct contact with your skin and moisten the electrodes for optimal performance. Keep the monitor on during the full session to track your heart rate accurately. The research team will monitor your session remotely to ensure you stay within the target heart rate zone

DEHYDRATION ASSESSMENT

1. Collect midstream urine in a clean cup
2. Dip strip for a second, remove excess, and keep it horizontal
3. Wait ~45 sec, then match color to the chart for specific gravity
4. Do not exercise if > 1.020-1.025

Please contact the study team if this occurs

IMPORTANT INFORMATION

HYDRATION

Stay well-hydrated during non-fasting hours.

1. Drink 2-3 liters of water between sunset (iftar) and dawn (suhoor).
2. Avoid excessive caffeine intake, as it can cause dehydration.

DAYLIGHT SAVING

The clock will move forward by one hour due to daylight saving time. Please continue to exercise during the hour before sunset (iftar) to lower the risk of dehydration.

SIGNS OF HEAT ILLNESS

If you choose to exercise remotely and notice heat exhaustion (heavy sweating - dizziness - headache)

- Stop exercising immediately.
- Move to a cool, shaded place.
- Rest, loosen clothing, and use a fan or cold towel.
- Sip water slowly once it is safe.
- Inform the study team right away.

If you notice heat stroke (dry skin - confusion - loss of coordination)

- Call 911 immediately.
- Move to a cool area.
- Apply cold towels or ice packs to neck, armpits, and groin.
- Stay with the person until help arrives.
- Notify the study team ASAP

Phone number
734-882-9518

Email address
Ramadan-study@umich.edu

Figure 5. Exercise Instructions

Appendix M. Individual Paired Data

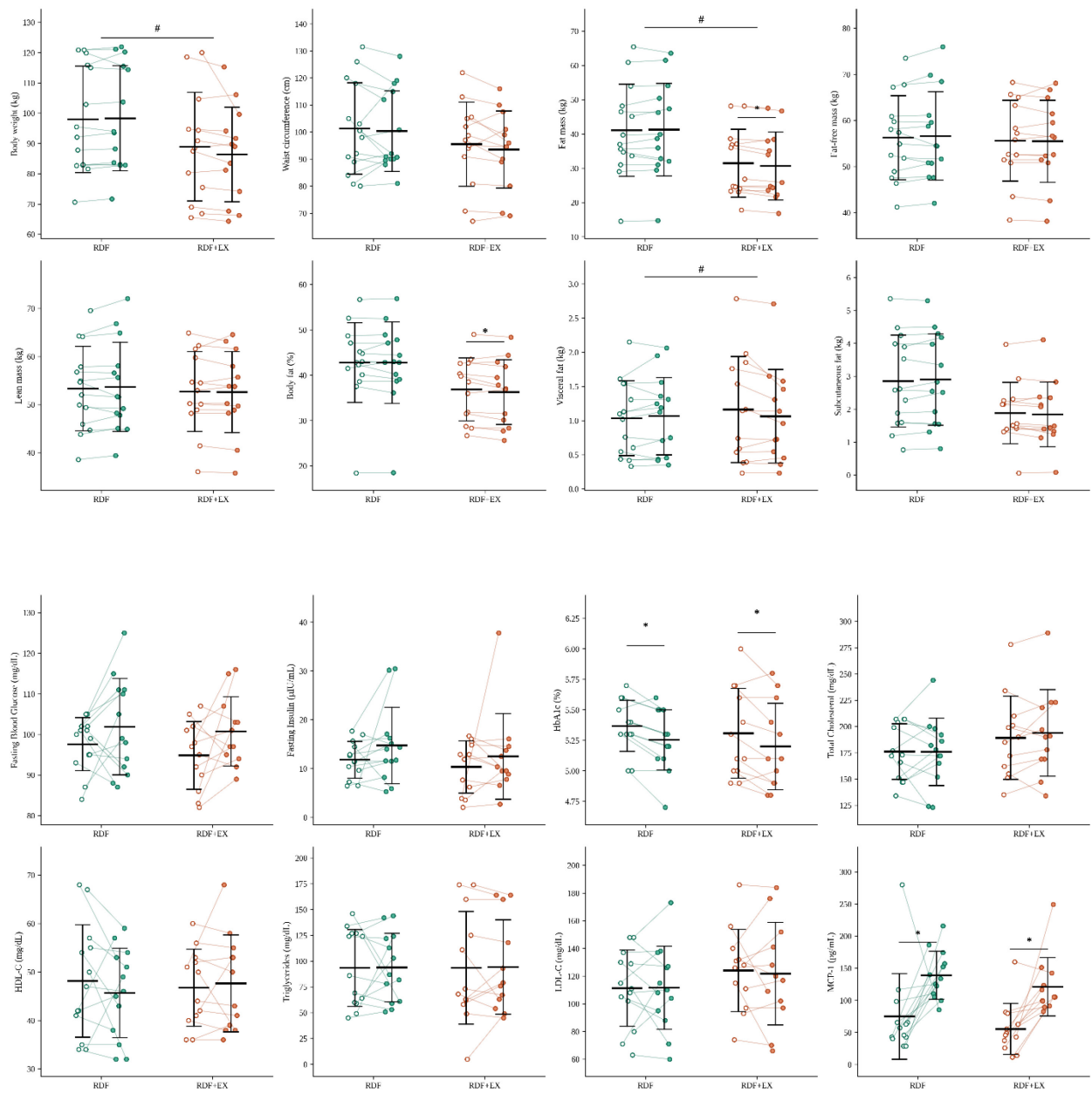


Figure 6. Individual Paired Data

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