Original Article

Cortical thickness, neurocognitive, and body composition effects of fasting during Ramadan

Muhammad Iqbal, Abdullah Abu Jamea[1], Miguel Alonso-Alonso[2], Khalid A. Al-Regaiey, Shahid Bashir[2,3]
Departments of Physiology and [1]Radiology, Faculty of Medicine, King Saud University, Riyadh, Saudi Arabia, [2]Center for the Study of Nutrition Medicine, Beth Israel Deaconess Medical Center, Laboratory of Bariatric and Nutritional Neuroscience, Harvard Medical School, Boston, Massachusetts, USA, [3]Neuroscience Center, King Fahad Specialist Hospital Dammam, Dammam, Saudi Arabia

Background: We aimed to study the anatomical, physiological, and cognitive function of healthy individuals practicing fasting during the month of Ramadan. Measurements were taken 1 week before and 2 weeks after Ramadan fasting. **Materials and Methods:** Twelve healthy male individuals (mean age ± standard error of the mean: 34.3 ± 2.9 years; body mass index: 26.26 ± 1.4 kg/m^2) were assessed for various parameters before and after Ramadan fasting. All the tests were performed in the morning. Body composition characteristics were assessed by bioelectrical impedance analysis using a commercially available body composition analyzer. For neurocognitive analysis, participants underwent the stop signal task (SST), pattern recognition memory task (PRM), and spatial working memory strategy (SWM) from the Cambridge Neuropsychological Test Automated Battery. T1-weighted, 1 mm-thick magnetic resonance images were also acquired. **Results:** Anthropometric analysis showed a significant decrease in body weight, fat-free mass (FFM), trunk FFM, and trunk predicted muscle mass, while the other body composition parameters did not exhibit any changes. The stop signal reaction time (SSRT) latency (ms) ($P > 0.05$) and PRM did not show any significant difference before and after fasting. SWM task ($P < 0.05$) improved significantly after fasting. Cortical thickness data of the whole brain were not significantly different after fasting at any brain location. There was a significant correlation between the left amygdala and the SWM strategy ($r^2 = 0.518$) and between fat and brain segmentation volume ($r^2 = 0.375$). **Conclusion:** Our pilot data suggest that Ramadan fasting leads to weight loss and FFM reductions and improve cognitive function.

Key words: Body composition, cognitive ability, neuroimaging, Ramadan fasting

How to cite this article: Iqbal M, Jamea AA, Alonso-Alonso M, Al-Regaiey KA, Bashir S. Cortical thickness, neurocognitive, and body composition effects of fasting during Ramadan. J Res Med Sci 2019;24:50.

INTRODUCTION

Fasting during Ramadan is an obligatory practice for Muslims worldwide. There are approximately 2 billion Muslims and hundreds of millions fast every year to abstain from eating, drinking, conjugal relationships, and smoking from sunrise until sunset as a sign of restraint and introspection in the 9th month of the lunar Islamic year for 29–30 days.[1] Depending on the season, that Ramadan coincides with and the location, the duration of fasting may vary between approximately 10 and 20 h. Fasting affects the circadian rhythm and the biorhythm of nutrient consumption, which results in changes in physiological, cognitive, behavioral, and metabolic functions, as well as sleep patterns.[2-4] The reported effects of fasting on body composition are inconsistent. Some studies have suggested an increase in body weight while others have reported a reduction, however, there have been no effects of fasting on both body weight and composition.[2,5] The variability in body weight has been attributed to the economic conditions of the society/country, age, sex, lifestyle, dietary intake, and a number of hours spent fasting.[6,7]

Alterations in the circadian rhythm influence cognitive function during fasting. The existing data on the effect of fasting on cognitive function vary. Some studies have suggested a decrease

Access this article online
Quick Response Code:
Website: www.jmsjournal.net
DOI: 10.4103/jrms.JRMS_783_18

Address for correspondence: Dr. Shahid Bashir, Neuroscience Center, King Fahad Specialist Hospital Dammam, Dammam, Saudi Arabia.
E-mail: sbashir10@gmail.com
Received: 19-11-2018; **Revised:** 26-12-2018; **Accepted:** 24-02-2019

in subjective alertness, psychomotor performance, and memory, while others have reported mixed responses depending on the time of the day, with better performance in the morning and poorer performance in the evening.[8,9] Other factors that affect cognition include food composition, particularly macronutrients, as well as the time of ingestion. Different types of food have different effects that result in either improved memory function or learning ability or impaired reaction time.[10] Hypoglycemia and accumulated sleep loss can also impair certain cognitive functions.[11]

Neuroimaging and other related techniques serve as important tools for understanding the brain systems linked to different aspects of brain functions such as cognition and behavior. A recent study that used diffusion tensor imaging suggested that microstructural changes occur following 3 weeks of fasting.[12]

In the literature, different brain locations associated with hunger and satiety have been identified. In a study that used positron emission tomography, hunger was shown to be associated with an increase in neuronal activity in the hypothalamus, thalamus, basal ganglia, temporal cortex, cerebellum, insula, anterior cingulate, and orbitofrontal cortex; and satiety was found to be related to increased neuronal activity in prefrontal cortex.[13,14]

Although previous studies have focused on the effect of Ramadan fasting on body composition, cognitive function, and neuroimaging, the cumulative effects of these parameters in any one setting have not previously been studied. Therefore, in this study, we aimed to assess the effect of 2 weeks of fasting on body composition, cognitive function, and neuroanatomical changes in healthy individuals.

MATERIALS AND METHODS

Subjects

Twelve healthy volunteers (mean age ± standard error of the mean [SEM]: 34.3 ± 2.9 years) took part in the present study. The individuals were nonsmokers and did not have a history of heart problems or diabetes. The individuals were enrolled in the study after receiving a verbal explanation regarding the research procedures and providing written informed consent. The study was conducted in 2014 after approval by the Local Ethics Committee of the College of Medicine, King Saud University, Riyadh, Saudi Arabia. Assessments were carried out at two different time points: 1 week before Ramadan and 2 weeks following Ramadan fasting. All the tests were performed in the morning. Ramadan started on June 28th and ended on July 27th and the approximate duration of fasting was just over a period of 16 h in Riyadh city. All the participants were residents of Riyadh and completed the study period, and they were their own controls.

Anthropometric measurements

Body composition was analyzed by bioelectrical impedance analysis using a commercially available Body Composition Analyzer (Type BC-418 MA, TANITA Corporation, Tokyo, Japan). The bioimpedance analyzer uses eight points of tactile electrodes with contacts at the hands and feet. The technique uses multiple frequencies to measure body mass index (BMI), total body water, fat, and fat-free mass (FFM) in total and segmental distributions in the trunk and limbs. The participants were asked to wipe out sole of the feet by a wet tissue and the stand over the electrodes of the machine and the data were recorded.

Cognitive function evaluate

Neuropsychological functions were assessed using the Cambridge Neuropsychological Test Automated Battery (CANTAB, http://www.cambridgecognition.com/cantab) research suite software (version 6. 0.37, Cambridge Cognition, Cambridge, UK). The responses were recorded with a touch-sensitive screen monitor. Each participant was given training trial to familiarize with the test before the actual test was taken. The entire battery required 25–30 min to complete the tests.

Stop signal task

The stop signal task (SST) is a task designed to measure response inhibitions and the response inhibition reaction time (impulse control). In this test, an arrow pointing left or right is shown on the screen. First, the participants were instructed to press on the corresponding (left/right) button on a press pad as soon as they see the direction of the arrow. In the next phase of the task, the participants were instructed to press on the corresponding button like before, but should not press the button when they hear a beep (the stop signal). The stop signal reaction time (SSRT) was calculated by subtracting the stop signal delay from the median go reaction time (the reaction time on trials with no stop signal). SSRT was selected as the main outcome measure.

Pattern recognition memory

The participant was presented with a series of 12 visual patterns at a time, displayed in the center of the screen. These patterns were designed not verbally labeled easily. In the recognition phase, the participant was required to choose between a pattern they had already seen and a novel pattern. In this phase, the test patterns were presented in the reverse order of the original order of presentation. The events were recorded as the number of correct responses, expressed as a percentage, with higher values indicating a better pattern of recognition memory (PRM Percentage correct measures).

Spatial working memory

Task

Spatial working memory (SWM) assesses the ability of participants to retain and update spatial information in working memory. This test is used to measure the heuristic strategy of participants. In this test, number of boxes was shown on the screen. The participant was told to search for tokens by opening the boxes by touching them. He was also advised not to open the box that had already shown a token. A between-search error was recorded when participants touched the box where a token had already been found, and this score was used as the measure for SWM (SWM-between errors). Once the token was found, the participant restarted the search using the sequence previously used. This task provided an indication of the participant's ability to use heuristic strategy. The evaluated events were SWM strategy (refers to number of times, the participant started a new search by touching a different box).

Image acquisition

A Siemens Magnetom Verio 3T magnetic resonance imaging (MRI) clinical scanner (Siemens AG, Healthcare Sector, Erlangen, Germany) and 12-channel phased-array head coil were used to acquire the following: (1) T1-weighted 3D magnetization prepared rapid gradient-echo imaging (TR = 1600 ms, TE = 2.19 ms, inversion time = 900 ms, flip angle = 9°, acquisition plane = sagittal, voxel size = 1 mm × 1 mm × 1 mm, FOV = 256 mm, acquired matrix = 256 × 256, and acceleration factor [iPAT] =2) and (2) fluid-attenuated inversion recovery (TR = 9000 ms, TE = 128 ms, inversion time = 2500 ms, flip angle = 150°, acquisition plane = axial, slice thickness = 5 mm, FOV = 220 mm, acquired matrix = 256 × 196, and acceleration factor [iPAT] =2).

We applied an independent component analysis to the resting state functional MRI (fMRI) series in 12-matched healthy controls. Imaging was performed on a Siemens Magnetom Verio 3T MRI. The resting state functional scans consisted of 404 volumes (repetition time = 1400 ms; echo time = 30 ms; flip angle = 65°; 64 axial slices; 64 × 64 matrix).

Data analysis was carried out using MELODIC from FMRIB's Software Library (FSL version 6.0; FSL, http://www.fmrib.ox.ac.uk/fsl) to identify the large-scale patterns of temporal signal intensity coherence. The detailed preprocessing procedure has been described previously.[15,16] Components of interest were selected by visual inspection based on previous studies.[17,18] The voxel-wise comparison of the resting functional connectivity in the between-subject analysis was carried out using a regression technique referred to as the "dual-regression" approach, as previously described.[15-17]

Statistical analysis

SPSS software (version 19.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. We used paired *t*-tests for the comparison of quantitative data between the Ramadan (fasting) and non-Ramadan (nonfasting) groups when the assumptions of normality were satisfied; otherwise, nonparametric tests were used. Two-tailed statistics ($P < 0.05$) were used as the level of statistical significance for all parameters.

RESULTS

Body composition analysis

Twelve male volunteers aged 34.33 ± 2.9 (mean ± SEM) years participated in the study. Tables 1 and 2 show the anthropometric analysis of different body composition parameters. There were statistically significant decreases in weight ($P = 0.019$), total body water ($P = 0.025$), FFM ($P = 0.021$), prefasting, and 1-week post-fasting. In the segmental analysis, trunk muscle mass ($P = 0.017$) and FFM ($P = 0.018$) were also decreased significantly. However, there were no significant differences among the other body characteristics.

Neuropsychological assessments

Cognitive analysis

The assessment of cognitive parameters is described in Table 3. The analysis of these parameters by CANTAB showed that the SWM task ($P = 0.025$) significantly improved after fasting [Table 3]. Other cognitive parameters such as SST and PRM did not show any statistically significant change in these parameters before and 2 weeks' post-Ramadan fasting [Table 3].

Magnetic resonance imaging

The neuroimaging analysis of the brain by MRI showed no significant differences in the major brain areas before

Table 1: Anthropometric analysis of body characteristics pre-Ramadan and 2-week post-Ramadan

Parameter	Pre-Ramadan	Post-Ramadan	*P*
Weight (kg)	80.55±4.13	79.65±4.31	0.019
Fat (%)	21.92±2.44	22.71±2.33	0.185
FM (kg)	18.54±2.75	19±2.78	0.379
FFM (kg)	62.04±2.01	60.66±6.51	0.021
TBW (kg)	45.41±3.4	44.4±2.1	0.025
VFR	7.75±1.48	7.75±1.42	1.000
Whole body	577.91±17.84	599.33±14.01	0.074
Leg (right)	252.25±9.6	259.33±7.69	0.156
Leg (left)	255.58±9.43	262.16±8.19	0.237
Arm (right)	303.66±12.77	315.25±11.56	0.178
Arm (left)	303.08±10.65	315.83±9.3	0.122

FM=Fat mass; FFM=Fat-free mass; TBW=Total body water; VFR=Visceral fat ratio

Table 2: Segmental body composition analysis pre-Ramadan and 2-week post-Ramadan

Parameter	Pre-Ramadan	Post-Ramadan	*P*
Right leg			
Fat (%)	18.05±2.84	19.67±2.19	0.324
FM (kg)	2.78±0.43	2.79±0.42	0.909
FFM (kg)	10.84±0.40	10.69±0.38	0.154
PMM (kg)	10.28±0.38	10.13±0.36	0.133
Left leg			
Fat (%)	18.17±2.70	19.57±1.91	0.384
FM (kg)	2.75±0.40	2.70±0.37	0.429
FFM (kg)	10.65±0.39	10.51±0.40	0.105
PMM (kg)	10.13±0.37	9.98±0.37	0.085
Right arm			
Fat (%)	18.88±2.66	21.04±2.37	0.274
FM (kg)	0.98±0.14	1.01±0.17	0.560
FFM (kg)	3.61±0.14	3.52±0.12	0.111
PMM (kg)	3.40±0.13	3.31±0.11	0.127
Left arm			
Fat (%)	20.89±2.18	21.74±2.49	0.373
FM (kg)	1.01±0.52	1.05±0.18	0.570
FFM (kg)	3.61±0.14	3.50±0.12	0.090
PMM (kg)	3.40±0.13	3.30±0.11	0.118
Trunk			
Fat (%)	21.81±3.36	24.74±2.63	0.198
FM (kg)	11.03±1.67	11.44±1.69	0.247
FFM (kg)	33.28±0.97	32.45±0.89	0.017
PMM (kg)	32.01±0.89	31.21±0.85	0.018

FM=Fat mass; FFM=Fat-free mass; PMM=Predicted muscle mass

Table 3: Analysis of cognitive parameters pre-Ramadan and 2-week post-Ramadan

Parameter	Pre-Ramadan	Post-Ramadan	*P*
PRM percent	86.37±1.08	85.59±1.34	0.252
SST SSRT	187.17±22.2	171.57±21.2	0.627
SST mean	463.35±31.12	424.80±15.22	0.177
SST direction	6.00±1.35	4.08±0.89	0.251
SST proportion	0.59±0.01	0.50±0.046	0.110
SSTSSD50	232.98±31.70	255.12±14.54	0.474
SWM between errors	19.83±1.93	18.08±2.08	0.072
SWM strategy	30.91±1.23	29.16±1.18	0.025

PRM=Pattern recognition memory; SST SSRT=Stop signal task stop signal reaction time; SWM=Spatial working memory; SSD=stop signal delay

and after fasting. There was a significant correlation between the left amygdala and SWM strategy [$r^2 = 0.518$, Figure 1], and between fat and the brain segmentation volume [$r^2 = 0.375$, Figure 2].

DISCUSSION

This study investigated physiological and neuropsychological alterations in a cohort of healthy individuals practicing Ramadan fasting. Changes in body composition have important implications for individual's health. Either these alterations lead to metabolic syndrome or body needs nutrients that are more essential. We have found that

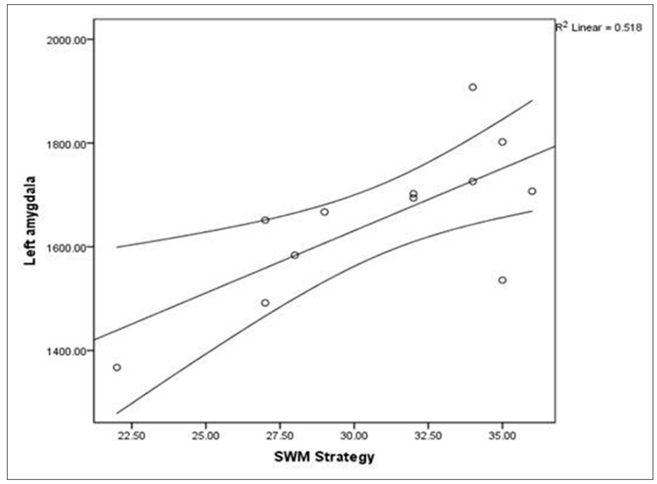

Figure 1: Correlation analysis between the left amygdala and spatial working memory strategy

anthropometric parameters such as weight, TBW, FFM, trunk FFM, and trunk PMM are decreased 2 weeks after fasting [Tables 1 and 2]. There are mixed reports on the effects of Ramadan fasting on different body composition parameters. Some studies have demonstrated a reduction in body weight, while others have reported an increase in body weight, or fasting does not have any effect on body weight.[5,6,16,19] There are various interpretations regarding weight reduction. In Ramadan, eating habits and meal times are changed. Calorie intake is increased in Ramadan, due to consumption of sugary foods and soft drinks, particularly during iftar times. However, there is an increase in physical activity such as mandatory night prayers "Terawih" which involve long period of standing and other religious activities. Thus, weight is reduced in Ramadan although calorie intake is increased. This reduction in weight loss is temporary and may be regained once the fasting period ends.[20]

Body composition analysis provides valuable information about muscle and body mass, which includes fat mass, FFM, and other body parameters. In our study, we have observed decrease in FFM, trunk FMM, and trunk PMM in all participants. There are variable findings about the effect of Ramadan fasting on body composition. Norouzy *et al*.[5] have found that Ramadan fasting has resulted in weight loss and FFM reduction in different age groups. However, the percent of body fat was lower only in male participants. A study by Karli *et al*.[21] had revealed that Ramadan fasting did not have significant changes in body weight, BMI, FFM, and percentage of body fat including other parameters. Contrary to this, Rohin *et al*.[22] found no significant effect on body composition in individual with different weight parameters. Another study by Sezen *et al*.[23] has found no effect on FFM in male volunteers, whereas visceral fat mass, BMI, and body fat mass were reduced. Our study group consists of participants of different age

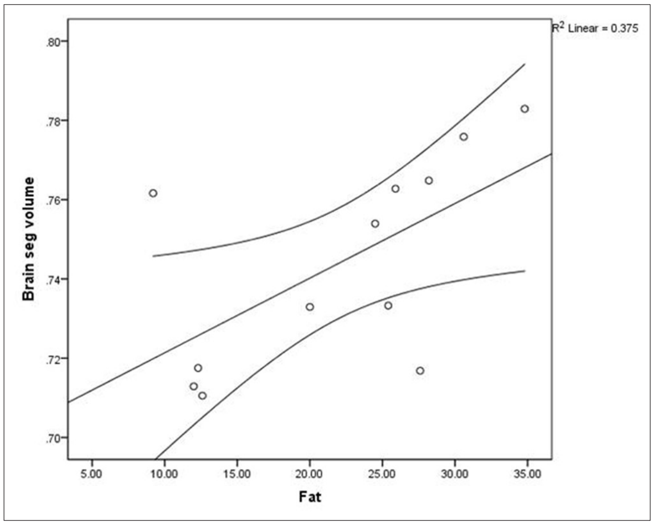

Figure 2: Correlation analysis between cortical thickness and fat percentage

groups; therefore, it is very difficult to draw any conclusion. Further studies with larger sample size are required to draw any constructive conclusion. The inconsistencies reported in our study and others may be related to variables associated with these types of research settings. For example, the age, sex, physical activity, types of food consumed, variability of fasting times in different geographical regions, seasonal and climatic differences in the month of Ramadan, and socioeconomic status of the fasting individual may affect the outcomes of these studies.

The accumulation of excessive body fat is associated with various health problems, such as type 2 diabetes, cancer, and cardiovascular disease.[23] We observed a positive correlation between body fat and cortical brain segmentation volume [Figure 1]. An increase in visceral adipose tissue (VAT) has been associated with a decrease in gray matter volume.[24] Cortical thickness is an appropriate measure of alterations in gray matter. Reduced cortical thickness is associated with an increase in BMI and VAT.[25] An increase in BMI has been shown to be associated with regional alterations in brain structure in the left lateral occipital cortex and right ventromedial prefrontal cortex. Previous neuroimaging studies have highlighted the crucial role of hunger and satiety centers and brain locations in the hypothalamus, insula, amygdala, middle temporal cortex, thalamus, and medial prefrontal cortex in relation to emotional regulation deficits.[26-30]

In the limbic system, the hypothalamus, thalamus, and amygdala have major roles in processing emotions and memory. The left amygdala was correlated with cognitive function in our study.[30] The amygdala is a brain structure involved in emotion and higher cognitive functions such as working memory and executive control.[31-33] We found a positive correlation between the amygdala and working memory in our participants [Figure 1]. One limitation of the present study was its small sample size, which may have been inadequate to detect statistical differences for some parameters. Furthermore, the present study could have been improved by using two groups with measurements made before, during, and after the fasting period. Another limitation of this study was that the cortical thickness-based analysis might have affected the estimated cortical thickness statistics. Finally, total abstinence from not only food but also fluids, during fasting can effect serum osmolality and eventually alter the intracellular water content and quantitative values of structures of the brain. A direct measure of body water content, such as serum osmolality should be used in future studies for the measurement of dehydration effects.

CONCLUSIONS

Our pilot data suggest that Ramadan fasting leads to weight loss and FFM reductions and to improve cognitive function.

Acknowledgments

The authors would like to thank the study participants, without whose co-operation it would not have been possible to conduct this study. The authors are also grateful to the Researchers Support and Services Unit at King Saud University for their technical support.

Financial support and sponsorship

Work on this study was supported by grants from the Deanship of Scientific Research Group (IRG14-10), King Saud University, Saudi Arabia.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Bahijri SM, Ajabnoor GM, Borai A, Al-Aama JY, Chrousos GP. Effect of Ramadan fasting in Saudi Arabia on serum bone profile and immunoglobulins. Ther Adv Endocrinol Metab 2015;6:223-32.
2. Bahijri S, Borai A, Ajabnoor G, Abdul Khaliq A, AlQassas I, Al-Shehri D, *et al*. Relative metabolic stability, but disrupted circadian cortisol secretion during the fasting month of Ramadan. PLoS One 2013;8:e60917.
3. Ibrahim WH, Habib HM, Jarrar AH, Al Baz SA. Effect of Ramadan fasting on markers of oxidative stress and serum biochemical markers of cellular damage in healthy subjects. Ann Nutr Metab 2008;53:175-81.
4. Yucel A, Degirmenci B, Acar M, Albayrak R, Haktanir A. The effect of fasting month of Ramadan on the abdominal fat distribution: Assessment by computed tomography. Tohoku J Exp Med 2004;204:179-87.
5. Norouzy A, Salehi M, Philippou E, Arabi H, Shiva F, Mehrnoosh S, *et al*. Effect of fasting in Ramadan on body composition and nutritional intake: A prospective study. J Hum Nutr Diet 2013;26 Suppl 1:97-104.
6. Salahuddin M, Sayed Ashfak AH, Syed SR, Badaam KM. Effect of Ramadan fasting on body weight, (BP) and biochemical parameters

in middle aged hypertensive subjects: An observational trial. J Clin Diagn Res 2014;8:16-8.
7. Tian HH, Aziz AR, Png W, Wahid MF, Yeo D, Constance Png AL, *et al.* Effects of fasting during Ramadan month on cognitive function in Muslim athletes. Asian J Sports Med 2011;2:145-53.
8. Roky R, Iraki L, HajKhlifa R, Lakhdar Ghazal N, Hakkou F. Daytime alertness, mood, psychomotor performances, and oral temperature during Ramadan intermittent fasting. Ann Nutr Metab 2000;44:101-7.
9. Leigh Gibson E, Green MW. Nutritional influences on cognitive function: Mechanisms of susceptibility. Nutr Res Rev 2002;15:169-206.
10. Roky R, Herrera CP, Ahmed Q. Sleep in athletes and the effects of Ramadan. J Sports Sci 2012;30 Suppl 1:S75-84.
11. Bakan AA, Yıldız S, Alkan A, Yetis H, Kurtcan S, Ilhan MM, *et al.* Microstructural effects of Ramadan fasting on the brain: A diffusion tensor imaging study. Diagn Interv Radiol 2015;21:256-61.
12. de Lauzon B, Romon M, Deschamps V, Lafay L, Borys JM, Karlsson J, *et al.* The three-factor eating questionnaire-R18 is able to distinguish among different eating patterns in a general population. J Nutr 2004;134:2372-80.
13. Tataranni PA, Gautier JF, Chen K, Uecker A, Bandy D, Salbe AD, *et al.* Neuroanatomical correlates of hunger and satiation in humans using positron emission tomography. Proc Natl Acad Sci U S A 1999;96:4569-74.
14. Del Parigi A, Gautier JF, Chen K, Salbe AD, Ravussin E, Reiman E, *et al.* Neuroimaging and obesity: Mapping the brain responses to hunger and satiation in humans using positron emission tomography. Ann N Y Acad Sci 2002;967:389-97.
15. Binnewijzend MA, Schoonheim MM, Sanz-Arigita E, Wink AM, van der Flier WM, Tolboom N, *et al.* Resting-state fMRI changes in Alzheimer's disease and mild cognitive impairment. Neurobiol Aging 2012;33:2018-28.
16. Beckmann CF, DeLuca M, Devlin JT, Smith SM. Investigations into resting-state connectivity using independent component analysis. Philos Trans R Soc Lond B Biol Sci 2005;360:1001-13.
17. Damoiseaux JS, Rombouts SA, Barkhof F, Scheltens P, Stam CJ, Smith SM, *et al.* Consistent resting-state networks across healthy subjects. Proc Natl Acad Sci U S A 2006;103:13848-53.
18. López-Bueno M, González-Jiménez E, Navarro-Prado S, Montero-Alonso MA, Schmidt-RioValle J. Influence of age and religious fasting on the body composition of Muslim women living in a westernized context. Nutr Hosp 2014;31:1067-73.
19. Farooq A, Herrera CP, Almudahka F, Mansour R. A prospective study of the physiological and neurobehavioral effects of Ramadan fasting in preteen and teenage boys. J Acad Nutr Diet 2015;115:889-97.
20. Fahrial Syam A, Suryani Sobur C, Abdullah M, Makmun D. Ramadan fasting decreases body fat but not protein mass. Int J Endocrinol Metab 2016;14:e29687.
21. Karli U, Guvenc A, Aslan A, Hazir T, Acikada C. Influence of Ramadan fasting on anaerobic performance and recovery following short time high intensity exercise. J Sports Sci Med 2007;6:490-7.
22. Rohin MA, Rozano N, Abd Hadi N, Mat Nor MN, Abdullah S, Dandinasivara Venkateshaiah M, *et al.* Anthropometry and body composition status during Ramadan among higher institution learning centre staffs with different body weight status. ScientificWorldJournal 2013;2013:308041.
23. Sezen Y, Altiparmak IH, Erkus ME, Kocarslan A, Kaya Z, Gunebakmaz O, *et al.* Effects of Ramadan fasting on body composition and arterial stiffness. J Pak Med Assoc 2016;66:1522-7.
24. Haslam DW, James WP. Obesity. Lancet 2005;366:1197-209.
25. Kurth F, Levitt JG, Phillips OR, Luders E, Woods RP, Mazziotta JC, *et al.* Relationships between gray matter, body mass index, and waist circumference in healthy adults. Hum Brain Mapp 2013;34:1737-46.
26. Veit R, Kullmann S, Heni M, Machann J, Häring HU, Fritsche A, *et al.* Reduced cortical thickness associated with visceral fat and BMI. Neuroimage Clin 2014;6:307-11.
27. Raschpichler M, Straatman K, Schroeter ML, Arelin K, Schlögl H, Fritzsch D, *et al.* Abdominal fat distribution and its relationship to brain changes: The differential effects of age on cerebellar structure and function: A cross-sectional, exploratory study. BMJ Open 2013;3. pii: e001915.
28. Medic N, Ziauddeen H, Ersche KD, Farooqi IS, Bullmore ET, Nathan PJ, *et al.* Increased body mass index is associated with specific regional alterations in brain structure. Int J Obes (Lond) 2016;40:1177-82.
29. Wable GS, Barbarich-Marsteller NC, Chowdhury TG, Sabaliauskas NA, Farb CR, Aoki C, *et al.* Excitatory synapses on dendritic shafts of the caudal basal amygdala exhibit elevated levels of GABAA receptor α4 subunits following the induction of activity-based anorexia. Synapse 2014;68:1-5.
30. Friederich HC, Walther S, Bendszus M, Biller A, Thomann P, Zeigermann S, *et al.* Grey matter abnormalities within cortico-limbic-striatal circuits in acute and weight-restored anorexia nervosa patients. Neuroimage 2012;59:1106-13.
31. Yau WY, Bischoff-Grethe A, Theilmann RJ, Torres L, Wagner A, Kaye WH, *et al.* Alterations in white matter microstructure in women recovered from anorexia nervosa. Int J Eat Disord 2013;46:701-8.
32. Takano A, Shiga T, Kitagawa N, Koyama T, Katoh C, Tsukamoto E, *et al.* Abnormal neuronal network in anorexia nervosa studied with I-123-IMP SPECT. Psychiatry Res 2001;107:45-50.
33. Schaefer A, Braver TS, Reynolds JR, Burgess GC, Yarkoni T, Gray JR, *et al.* Individual differences in amygdala activity predict response speed during working memory. J Neurosci 2006;26:10120-8.