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ORIGINAL RESEARCH

Exploring Mindfulness and Mindful Eating and Visual Attention Towards Food Cues: Preliminary Findings

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Abstract
Continual exposure to energy dense foods is suggested to promote overeating and obesity. The aim of the present research was to explore whether or not mindfulness could reduce visual attention towards food cues. In two laboratory studies, participants with a normal weight range completed an eye-tracking paradigm, and their eye-movements were recorded. In study 1, participants were exposed to either mindfulness meditation or a control condition, and their eye-movements towards low energy density (LED) vs high energy density (HED) food cues were measured. In study 2, participants were assigned to a mindful eating condition using a Mindful Construal Diary (MCD) or a control condition, and their eye-movements towards LED or HED food vs. non-food cues were recorded. In study 1, participants in the mindfulness meditation condition had greater attention duration towards LED food cues, whilst those in the control condition exhibited greater attention duration towards HED food cues. In study 2, there were no significant differences in the maintenance of attentional biases towards food cues between the two conditions. Mindfulness meditation may be beneficial in increasing attention towards LED food cues. Future research should further explore the effect of mindfulness and mindful eating on visual attention towards food cues with people who suffer from excess weight or have obesity, and also within naturalistic settings.

Keywords Visual attention · Mindfulness · Mindful eating · Food cues

The worldwide obesity epidemic is partially the result of the existent "obesogenic" environment, which is characterised by easily accessible, extensively advertised palatable and high energy density (HED) food items (Blundell et al., 2005; Swinburn et al., 2011; Werthmann et al., 2011). Exposure to such foods and visual food related cues is proposed to stimulate food cravings, food intake, and in effect, weight gain (Polivy et al., 2008). Therefore, exploring strategies that modify attentional biases towards food cues is essential to promote healthier eating behaviours.

Attentional biases for food related cues can be directly assessed using eye-tracking technology, and a number of studies have been conducted utilising eye-tracking methods to explore attentional processes around food stimuli (e.g. Baschnagel, 2013; Henderson & Hollingworth, 1998; Popien et al., 2015). For example, researchers have previously explored attentional biases between participants who are of a normal weight and those who suffer from excess weight or have obesity, and found participants who have obesity exhibiting greater initial and maintained attention towards HED food images compared to non-food images than participants who are of a normal weight (Castellanos et al., 2009; Doolan et al., 2014; Nijs, Franken, et al., 2010; Werthmann et al., 2011). Similarly, participants with obesity and binge eating disorder display increased attentional bias towards food cues compared to participants with obesity but without binge eating disorder (Deluchi et al., 2017).

More specifically, studies have examined the association between attentional biases towards HED foods and unhealthy eating, and findings have indicated a positive correlation between attention bias for HED foods and subsequent consumption of such foods, as well as increased BMI (Calitri et al., 2010; Nijs, Muris, et al., 2010). Research has suggested that changing attentional biases, particularly decreasing attentional biases for HED foods may assist in reducing consumption of unhealthy foods

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(Berridge, 2009; Kemps et al., 2014) . For example, Kakoschke et al. (2014) trained participants to direct their attention either towards low energy density (LED) or HED food cues, and found participants who attended to LED food cues increased their attention bias and consumed more healthy (than unhealthy) snacks in comparison to those who attended HED food cues. Such findings suggest that inducing attentional bias for LED foods may translate into the consumption of healthier foods (Kemps et al., 2014; Kakoschke et al., 2014), making attentional training an effective method in promoting healthier eating behaviours. Manipulating attentional biases around food is feasible and has been explored in behavioural research that investigated consumption and memory in attentive and mindful eating experiments (Higgs, 2015; Dutt et al., 2019) .

Mindfulness is a construct that could potentially modify attentional biases towards food cues. The concept of mindfulness has been described as an awareness that emerges through purposefully paying attention to what is taking place in the present moment with a non-judgmental attitude (Kabat-Zinn, 1990). Over recent years, mindfulness has been suggested to be an effective strategy in promoting healthier eating behaviours through increased intake of fruit, reduced consumption of HED foods and control of impulsive reactions towards attractive but unhealthy foods (Dutt et al., 2019; Jenkins & Tapper, 2014; Jordan et al., 2014; Papies et al., 2012). Engaging in mindfulness practices can help to increase observation of internal states, focusing on hunger and satiety, and moving away from external cues, this improves the ability to monitor and regulate dietary intake (Mantzios & Wilson, 2015; Ouwens et al., 2015; Walach et al., 2006). As a result of successfully promoting healthier eating behaviours, mindfulness-based interventions have also led to weight loss (Dalen et al., 2010; Daubenmier et al., 2011; Mantzios & Giannou, 2014; Mantzios & Wilson, 2015; Warren et al., 2017). The component of mindfulness that involves observing thoughts and experiences without the tendency to react or judge allows for the re-direction of attention back to the current focus, prompting one's ability to successfully disengage from distracting stimuli (Semple, 2010; Sumantry & Stewart, 2021). As such, mindfulness can enhance attentional abilities, such as switching and maintaining attentional engagement, and be effective in diminishing attentional biases towards unhealthy stimuli (Garland et al., 2012). For example, when exposed to attractive foods, one may experience stimulations of eating the food and/or the accompanied instant gratification. However, mindfulness enables the perception of reactions to the attractive foods as mere mental events, where additional meaning is not attached to them, thus moving attention away from those stimuli and facilitating self-regulation (Papies et al., 2012). Research supporting this notion has found mindfulness to reduce attentional bias towards attractive but unhealthy stimuli, such as food and alcohol (Garland et al., 2012; Papies et al., 2012).

Despite the established success of mindfulness interventions in promoting healthier eating behaviours and weight loss, there is little existing literature exploring the effect of mindfulness on attentional biases towards food cues. Therefore, the present study aimed to address this gap through evaluating attentional processes towards food cues after engaging in mindfulness meditation. First, it was hypothesised that engaging in mindfulness meditation would significantly increase state mindfulness when compared to the control condition. Second, it was predicted that participants in the mindfulness meditation condition would exhibit a greater attentional bias towards LED foods, whilst those in the control condition would display a higher bias towards HED foods.

Study 1

Method

Participants

Researchers recruited participants from a university in West Midlands, UK, via an online research participation scheme at the institution, and they received course credit for their participation. The sample consisted of 20 participants with an average BMI of $M = 22.28$ ($SD = 5.14$) and age of $M = 21.85$ ($SD = 3.18$). Participants self-identified ethnicities were as follows: White or White British ($n = 14$), South Asian ($n = 4$), Polynesian ($n = 1$) and not-specified ($n = 1$). The university ethics committee approved the study, and informed consent was obtained from all participants.

Eligibility Due to the nature of the study (i.e. attentional biases towards food cues), participants were informed via an information sheet and consent form that they were not eligible to participate if they had been diagnosed with an eating disorder, had any food allergies/intolerances, or special dietary requirements.

Experimental Conditions

Participants were alternately allocated to either the mindfulness meditation condition ($n = 10$; female = 7, male = 3) or the control condition ($n = 10$; female = 8, male = 2). Participants in the mindfulness meditation condition received an audio file on 'Mindfulness Breathing Meditation' (Mantzios, 2018) lasting approximately 10 min (see "Mindfulness Breathing Meditation Exercise" for further detail). Whilst those in the control condition received an audio file on "Natural History of Selbourne" (White, 2008) also lasting approximately 10 min, and this audio file was chosen as it has been similarly used in other related research (e.g. Zeidan et al., 2015).

Measures

Participant Demographic Form Participants answered questions regarding their gender, age, height, weight and ethnicity in order to assess their BMI and background information.

Hunger To assess hunger, participants were asked at the start of the experimental session "How hungry do you feel right now?" with responses ranging from 1 (*not at all)* to 5 *(extremely hungry*).

State Mindfulness Scale (SMS; Tanay & Bernstein, 2013) The SMS is a 21-item tool that reflects on traditional and contemporary psychological science models of mindfulness. Responses range from 1 (*not at all*) to 5 (*very well*), with total scores varying from 21 to 105, and higher scores indicating higher levels of state mindfulness. Sample items include "I clearly physically felt what was going on in my body" and "I noticed pleasant and unpleasant thoughts". Participants completed the SMS before (pre) and after (post) engaging with the reading materials (i.e. MCD or newspaper article). The present study produced an alpha of pre—($\alpha = 0.95$) and post—($\alpha = 0.98$).

Mindfulness Breathing Meditation Exercise

The mindfulness breathing meditation practice (Mantzios, 2018) instructed participants to attend to their breathing and accompanied physical sensations, without changing or altering their breath in any manner. Participants were also encouraged to notice when their mind wandered, and to non-judgmentally return their attention back to their breathing. This 10-min audio recording employed the key features of mindfulness practice, focusing on present moment and acceptance (Kabat-Zinn, 1990) and has been used in other mindfulness literature (Bennett et al., 2018; Dutt et al., 2019; Ilies et al., 2019; Sprawson et al., 2020). The full script to the mindfulness breathing meditation exercise (Mantzios, 2018) can be made available upon request to the corresponding author.

Visual Task: Free Exploration Paradigm

Eye-movement data was collected using a Tobii Pro X3-120 screen-based eye-tracker (Tobii Technology, Stockholm, Sweden). Participants were seated in front of the Tobii screen-based eye-tracker at a distance of approximately 60 cm, and a 9-point calibration with subsequent validation procedure was conducted for each participant prior to the visual task. After calibration, each trial started with a central fixation cross for 1000 ms, followed by an image pair containing HED and LED foods for 2000 ms (see Fig. 1). Participants were instructed to look at the fixation cross at the start of each trial and then freely explore the following stimuli presented (Hummel et al., 2018; Schag et al., 2013; Schmidt et al., 2016). There were a total of 20 trials during the task, and the selection of food items contained both sweet and savoury foods, such as burgers and cakes (HED foods) and broccoli and bell peppers (LED foods). The order of trials were randomised for each participant, and within each trial, HED and LED foods appeared equally on the left or right side of the screen. All images used in the visual task had a resolution of 600×450 pixels, and were taken from a database designed for experimental research on eating and appetite (Blechert et al., 2014), and each HED and LED food image pair was closely matched for its colour, size and complexity.

Procedure

The study was advertised as an experiment exploring attentional processes towards food cues, and was deliberately kept vague in order to prevent participants from predicting the true aim of the study. Experimental sessions took place between 10am and 3 pm, lasting approximately 20 min. Upon arrival, participants received an information sheet, and after providing informed consent, their height and weight was measured using a stadiometer and digital scale. Next, participants completed demographic questions, a hunger measure and SMS. Once participants completed those measures, they were asked to use the headphones provided to them to either listen to the Mindfulness Breathing Meditation audio file (mindfulness condition) or the Natural History of Selbourne audio file (control condition). Next, participants completed another SMS, and were instructed to complete the visual task (as discussed under "Experimental

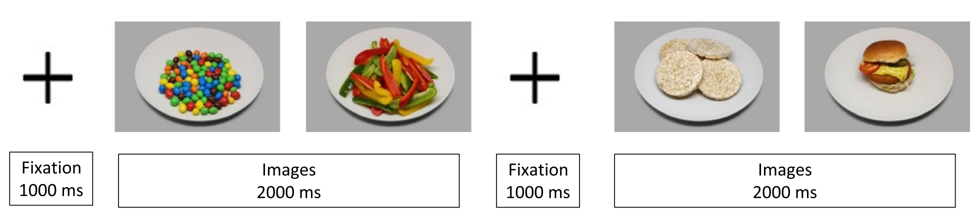

Fig. 1 Example of trials. A fixation cross is shown in the middle of the screen (for 1000 ms) followed with a HED vs LED food trial (for 2000 ms) and LED vs HED food trial (for 2000 ms)

Task"). After finishing the visual task, participants were debriefed and thanked for their participation.

Data Preparation: Free Exploration Visual Task

Each participant was shown a total of 20 trials (20 LED food images vs 20 HED food images). All eye-movement data collected from participants was viable as no calibration difficulties were experienced. Gaze duration was the dependent measures that was obtained from the eye-movement data. To measure gaze duration (i.e. maintained attention), two measures were taken, average fixation duration (ms) and total fixation duration (ms). The two measures were calculated by subtracting the mean gazing time on HED food images from mean gazing time on LED food images and gaining a difference score, whereby a positive score reflected longer maintained attention on LED image than on HED food image, and a negative score indicated longer attentional maintenance on HED food image than on LED food image (Schmidt et al., 2016; Sperling et al., 2017).

Data Analysis

ANOVAs (2 × 2) were conducted to test for differences in state mindfulness, and *t*-tests were run to explore differences in gaze duration. Participants' hunger and BMI was also tested as covariates using ANCOVA to assess whether they had any effect on the dependent variables. All analyses were conducted using SPSS v24.

Results

Participant Characteristics

As shown in Table 1, participants were well matched across the two conditions on gender, hunger, BMI and age. Inclusion of participants' hunger and BMI as covariates in the analyses did not affect the observed results for any of the dependent measures.

Table 1 Measures of participant hunger and characteristics between mindfulness and control conditions

	M (*SD*)—mindfulness (*n* = 10)	*M* (*SD*)—control (*n* = 10)
Gender		
Female	7	8
Male	3	2
Hunger	2.40 (1.26)	2.33 (.87)
BMI	23.20 (6.60)	21.35 (3.20)
Age	21.70 (2.00)	22.00 (4.16)

M and *SD* are used to represent mean and standard deviation, respectively

State Mindfulness

A 2 (condition: mindfulness, control) × 2 (time: pre, post) mixed design ANOVA was carried out to explore the effect of the mindfulness meditation on state mindfulness. There was a significant interaction between condition and time $F(1,18) = 8.38$, $p = 0.01$, $\eta_p^2 = 0.32$, with mindfulness scores increasing significantly amongst participants within the post mindfulness meditation condition. There was a significant main effect for time $F(1, 18) = 16.54$, $p = 0.001$, $\eta_p^2 = 0.48$, with increase in scores being demonstrated during post time, but no significant main effect between conditions $F(1, 18) = 1.34$, $p = 0.26$ (see Table 2).

Gaze Duration

Independent sample *t*-tests were conducted to compare average fixation duration and total fixation duration between the mindfulness meditation condition and control condition. There was a significant difference between the mindfulness meditation condition and control condition for the average fixation duration $t\ (18) = 2.47$, $p = 0.02$, $d = 1.10$ and total fixation duration $t\ (18) = 4.47$, $p < 0.001$, $d = 2.00$, with participants in the mindfulness meditation condition maintain attention more on LED food images compared to participants in the control condition fixating more on HED food images (see Table 3).

Exploratory Analyses: Associations Between Attentional Measures, Hunger and BMI

Pearson's correlations between attentional measures, hunger and BMI found no significant associations.

Discussion

The findings from study 1 suggested participants in the mindfulness meditation condition improved significantly on their state mindfulness compared to those in the control condition. Further in support of the hypotheses, the results from the eye-movement data demonstrated participants in the mindfulness condition had greater attention duration towards LED food, whilst those in the control condition exhibited

Table 2 Pre- and post-measures of SMS between mindfulness and control conditions

	M (*SD*)—mindfulness (*n* = 10)	*M* (*SD*)—control (*n* = 10)
Pre	58.80 (20.20)	66.30 (13.27)
Post	89.70 (4.30)	71.50 (14.83)

M and *SD* are used to represent mean and standard deviation, respectively

Table 3 Attention measures of participants between mindfulness and control conditions

Measure	Mindfulness ($n=10$)	Control ($n=10$)
Gaze direction bias	.53	.49
Gaze duration		
Average fixation (ms)		
LED	.21 (.06)	.23 (.07)
HED	.18 (.04)	.23 (.07)
Average fixation (difference)	.02 (.02)	.00 (.02)
Total fixation (ms)		
LED	143.67 (60.33)	110.67 (26.48)
HED	53.14 (20.89)	125.21 (47.98)
Total fixation (difference)	90.52 (57.60)	− 14.53 (47.09)

M and *SD* are used to represent mean and standard deviation, respectively
LED low energy density, *HED* high energy density

greater attention duration towards HED food images. Participants' hunger and BMI displayed no significant effect on the findings. This was the first study to investigate the effect of mindfulness on attentional biases towards food cues, and the findings are indeed consistent with similar literature exploring eating behaviour and consumption (e.g. Dutt et al., 2019; Jordan et al., 2014; Tapper & Turner, 2018).

Study 2

Whilst the findings of mindfulness meditation modifying attentional biases are positive, there has been some research that has suggested generic mindfulness practices, such as mindfulness meditation may not necessarily achieve regulation around food (Marchiori & Papies, 2014) as they are not eating-specific practices (Mantzios & Wilson, 2015). Furthermore, mindfulness meditation is sometimes viewed as an additional chore that is effortful and time consuming. The effort required to engage in mindfulness meditation can be a barrier which reduces the effectiveness of such interventions in regulating eating behaviour and weight management (Mantzios & Wilson, 2015). Instead, mindful eating proposes a more specific direction toward making eating interventions more effective.

Mindful eating involves applying mindfulness principles to food-related behaviours, whereby one would pay purposeful attention to the present meal or snack with a non-judgemental or accepting attitude (Mantzios, 2020; Mantzios & Wilson, 2015). Research has shown that mindful eating assists in the gradual change of external to internal eating, improving the ability to monitor and regulate dietary intake (Mantzios & Giannou, 2014; Mantzios & Wilson, 2014; Mantzios et al., 2019). For example, Allirot et al. (2018) found a brief mindful eating induction subsequently led participants to eat a reduced number of HED foods. Similarly, participants who ate their lunch mindfully by focusing on the sensory characteristics (of the meal), later consumed significantly fewer cookies than those who were in a control condition (Higgs & Donohoe, 2011; Robinson et al., 2014). In another study, van de Veer et al. (2016) found that participants who attended to their bodily sensations were more likely to compensate for their previous consumption by consuming fewer cookies. Other research has also found that mindfully eating desired or undesired snacks can significantly increase the enjoyment of those foods (Arch et al., 2016; Hong et al., 2011, 2014). Moreover, Mantzios et al. (2019) explored chocolate intake, and found those who participated in a mindful raisin exercise consumed significantly less chocolate than those who did not. Cross-sectional research has also found similar findings with mindful eating being negatively associated with fat and sugar consumption, motives to eat palatable foods, grazing, emotional eating, and weight gain (Egan et al., 2021; Mantzios, 2014; Mantzios et al., 2018a, 2018b, 2018c). However, other research has found conflicting findings. For example, Seguias and Tapper (2022) found eating mindfully by attending to the sensory properties of one's food did not result in any significant differences in energy intake over a three day period, nor over a half day period (Tapper & Seguias, 2020), and neither did it result in a reduction in later food intake (Whitelock et al., 2018). Similarly, Cavanagh et al. (2014) found mindful eating did not result in any significant reductions in portion size consumption. As such, it can be somewhat difficult to determine how effective mindful eating can be in reducing energy intake, promoting healthier eating behaviours and weight loss, and further identification of the mechanisms of behavioural change are needed.

One example of a mindful eating tool that has shown previous success in promoting mindful eating is the Mindful Construal Diary (MCD; Mantzios & Wilson, 2014). The MCD combines the concept of mindfulness, self-compassion and construal level theory (CLT; Mantzios & Wilson, 2014) and requires participants to simply consider the answers to the MCD items whilst eating (e.g. Hussein et al., 2017). CLT focuses on the *how* elements of one's behaviour, fostering present centred awareness and requiring minimum judgment and rumination (Mantzios & Wilson, 2014). Studies exploring the MCD have shown significant improvements in eating behaviour, weight loss, mindfulness, self-compassion and anxiety (Hussain et al., 2021a, 2021b, 2021c; Hussein et al., 2017; Mantzios & Wilson, 2014; Mantzios et al., 2020). In addition, a recent study found MCD to be as effective in reducing chocolate intake as the mindful raisin eating practice (Mantzios et al., 2020) when exposed in a mindless eating environment, but whether the MCD can reduce attentional biases towards food cues has not yet been explored.

It has been suggested the visualisation of HED foods or food cues activates reward pathways within brain regions (Berridge, 2009; Volkow & Wise, 2005). This concept stems from the incentive sensitization theory (Franken, 2003; Robinson & Berridge, 1993), which suggests that sensitization of the dopaminergic reward system increases the salience of reward related cues in the environment (e.g. HED foods), making them more appealing, thereby promoting cravings and consumption (Nijs & Franken, 2012; Robinson & Berridge, 2003). Some previous literature has found participants' attentional bias towards HED food images to be greater when compared to LED food images, regardless of hunger and BMI levels (e.g. Castellanos et al., 2009; Doolan et al., 2014; Nijs & Franken, 2012; Werthmann et al., 2011). While study 1 measured hunger and BMI when exploring attentional biases towards food cues, study 2 also measured fat and sugar consumption. Considering the limitations of contemplative practices that are not specific to eating, study 2 utilised the MCD mindful eating practice previously found to be effective in reducing intake and enabling weight loss. It was firstly hypothesised that using the MCD would significantly increase state mindfulness when compared to the control condition. Second, it was predicted that all participants will display a greater initial attention towards HED food images than LED food images, but participants using the MCD would exhibit a reduced maintained attentional bias towards food cues than control participants.

Method

Participants

As in study 1, participants attending a university in West Midlands, UK, were recruited via an online research participation scheme at the institution, and they received course credit for their participation. Six participants were excluded from the final analysis because of missing data (see "Data Preparation—Visual Task"). The final sample consisted of 44 participants with an average BMI of $M = 24.44$ ($SD = 4.67$) and age of $M = 23.61$ ($SD = 6.87$). Participants self-identified ethnicities were: White or White British ($n = 21$), Black African or Caribbean ($n = 5$), South Asian ($n = 10$), Chinese ($n = 3$), mixed ethnicity ($n = 4$) and not specified ($n = 1$). The university ethics committee approved the study, and informed consent was gained from all participants.

Eligibility. Due to the nature of the study (i.e. attentional biases towards food cues), participants were informed via an information sheet and consent form that they were not eligible to participate if they had been diagnosed with an eating disorder, had any food allergies/intolerances, or special dietary requirements.

Experiment Conditions

Participants were alternately allocated to either the mindful eating condition ($n = 22$; female = 21, male = 1) or the control condition ($n = 22$; female = 17, male = 5). Participants in the mindful eating condition received a modified version of the original MCD (Mantzios et al., 2020). The modified MCD was initially developed for chocolate consumption (Mantzios et al., 2020), but for the purpose of this study, "chocolate" was simply rephrased to "raisin" (see Table 4). Participants were asked to simply consider (instead of write) the answers to the questions of the modified MCD (Hussein et al., 2017; Mantzios et al., 2020). The script for the MCD is available in the supplementary materials of Mantzios et al. (2020) and can also be made available upon request to the corresponding author. In the control condition, participants received a newspaper article concerning carbon emission of similar length to the modified MCD and with no food or eating-related matter (Robinson et al., 2014).

Measures

For demographic questions, hunger and SMS, see study 1. For the SMS, study 2 produced an alpha of pre—($\alpha = 0.93$) and post—($\alpha = 0.93$).

Dietary Fat and Free Sugar—Short Questionnaire (DFS; Francis & Stevenson, 2013). The DFS-SF is a 26-item scale measuring dietary fat and sugar intake. Twenty-four items of the DFS-SQ require participants to recall the frequency of consumption of food groups eaten in the last 12 months, and the last two items are

Table 4 Questions presented to participants in the mindfulness condition

Mindful Construal Diary-Raisin (MCD-R)
How does it smell?
What is the texture of it?
How does it taste?
How patient am I now that thoughts and feelings are not allowing me to experience the pleasure of eating this raisin?
How important is it for me and all people to experience and eat raisin this way?
How is this snack important right now?

concerned with the frequency of eating away from home and the added sugar to food and beverages. Sample items include "Fried chicken or chicken burgers" (fat) and "Cakes, cookies" (sugar). Responses range from "1 per month or less" to "5 + per week", and overall scores range from 26 to 130. The present study produced an overall alpha of (α = 0.74).

Experimental Task / Visual Task: Free Exploration Paradigm

The pictorial stimuli used in the critical trials consisted of 20 LED food images (e.g. banana, green beans) and 20 HED food images (e.g. doughnuts, burger). Each food image was closely matched with a non-food image for colour, size and complexity, and included items such as tools and stationery (Castellanos et al., 2009; Doolan et al., 2014). An additional 20 images of nature scenes unrelated to food were used as filler images, and were randomly paired with both food and non-food images to vary the task and reduce monotony (Castellanos et al., 2009). All images used in the filler trials were different from those used in the critical trials, and each stimulus was presented equally often on the left and right side of the screen. Eye-movement data was collected using a Tobii Pro X3-120 screen based eye-tracker (Tobii Technology, Stockholm, Sweden). Participants were seated in front of the Tobii screen based eye-tracker at a distance of approximately 60 cm, and a 9-point calibration with subsequent validation procedure was conducted for each participant prior to the visual task. After calibration, each trial began with a central fixation cross for 1000 ms, followed by the image pairs for 2000 ms (see Fig. 1). Participants were instructed to look at the fixation cross at the start of each trial and then freely explore the following stimuli presented (Hummel et al., 2018; Schag et al., 2013; Schmidt et al., 2016). The order of trials was randomised for each participant. All food and non-food images used in the visual task had a resolution of 600 × 450 pixels and were taken from a database designed for experimental research on eating and appetite (Blechert et al., 2014) (Fig. 2).

Procedure

The study was advertised as an experiment investigating the effect of consumption on attention biases towards different images, such as stationary, nature and food, and was deliberately kept vague in order to prevent participants from predicting the true aim of the study. Experimental sessions took place between 10 am and 3 pm, lasting approximately 20 min. Upon arrival, participants received an information sheet, and after providing informed consent, their height and weight was measured using a stadiometer and digital scale. Next, participants completed demographic questions, a hunger measure and SMS. Once participants completed those measures, they were asked to either read the modified MCD (mindful eating condition) or a newspaper article (control condition) for 1 min prior to receiving a raisin. Participants were then provided with a single raisin in a bowl and continued engaging with either the MCD or newspaper article for another 3 min whilst eating their raisin. Next, participants completed another SMS and were instructed to complete the visual task (as discussed under "Experimental Task"). After finishing the visual task, participants completed the DFS scale, and they were debriefed and thanked for their participation.

Data Preparation—Visual Task

Each participant was shown a total of 60 trials (20 LED food images vs non-food images; 20 HED food vs non-food images; 20 fillers vs food and non-food images). Eye-movement data from filler trials was discarded. No eye-movement data was collected for six participants (mindfulness $n = 3$; control $n = 3$) because of calibration difficulties. The dependent measures obtained from the eye-movement data were gaze direction bias and graze duration bias (Castellanos et al., 2009; Doolan et al., 2014; Nijs, Muris, et al., 2010). Gaze direction bias is the initial attentional orientation and was calculated using the number of trials in which the first fixation was directed towards a food image as a proportion of all trials in which the first fixation was made to either the food or non-food image (direction bias score: > 0.5 reflects orientating bias towards food images; = 0.5 indicates no bias; < 0.5 represents orientating bias towards non-food images). Similar to study 1, gaze duration bias was calculated for two measures, average fixation duration and total

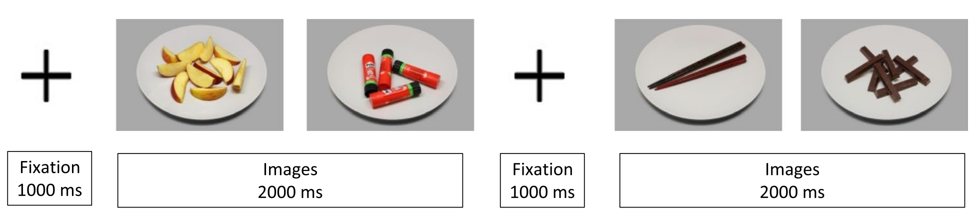

Fig. 2 Example of trials. A fixation cross is shown in the middle of the screen (for 1000 ms) followed with a LED vs non-food trial (for 2000 ms) and HED vs non-food trial (for 2000 ms)

fixation duration. Both measures were calculated using the average or total gaze duration towards a food image across all trials as a proportion of the average or total gaze duration to all food and non-food images (duration bias score: > 0.5 reflects maintained attention towards food images; = 0.5 indicates no bias; < 0.5 represents maintained attention towards non-food images).

Data Analysis

ANOVAs (2 × 2) were conducted to test for differences in state mindfulness, gaze direction bias and gaze duration bias between the two conditions. Participants' hunger, BMI, and fat and sugar consumption were also tested as covariates using ANCOVA to assess whether they had any effect on the dependent variables. All analyses was conducted using SPSS v24.

Results

Participant Characteristics

As shown in Table 5, participants were well matched across the two conditions on gender and BMI. Participants in the control condition were slightly hungrier than those in the experimental condition, and participants in the control condition were also slightly older. Inclusion of participants' hunger, BMI, fat and sugar consumption, and age as covariates in the analyses did not affect the observed results for any of the dependent measures.

State Mindfulness

A 2 (condition: mindful eating, control) × 2 (time: pre, post) mixed design ANOVA was carried out to explore the effects of the MCD on state mindfulness. There was a significant interaction between condition and time $F(1, 42) = 5.40$, $p = 0.03$, $\eta_p^2 = 0.11$, with mindfulness scores increasing significantly amongst participants within the post mindful eating condition. There was a significant main effect for time $F(1, 42) = 7.10$, $p = 0.01$, $\eta_p^2 = 0.15$, but no significant main effect between conditions $F(1, 42) = 0.10$, $p = 0.76$ (see Table 6).

Table 5 Measures of participant hunger and characteristics between mindfulness and control conditions

	M (*SD*)—mindfulness (*n* = 22)	*M* (*SD*)—control (*n* = 22)
Gender		
Female	21	17
Male	1	5
Hunger	1.64 (.79)	2.14 (.89)
BMI	23.82 (4.47)	25.03 (4.89)
Age*	21.45 (3.42)	25.77 (8.67)

M and *SD* are used to represent mean and standard deviation, respectively

*Significant difference between conditions

Gaze Directional Bias

A 2 (condition: mindfulness, control) × 2 (food image energy density: LED, HED) mixed design ANOVA was carried out, with the condition being a between subjects factor and food image energy density being a repeated measures factor (see Table 4). There was a significant main effect for food image energy density $F(1, 42) = 4.83$, $p = 0.03$, $\eta_p^2 = 0.10$, with all participants regardless of condition demonstrating greater bias towards HED food images ($M = 0.52$, $SD = 0.16$) than LED food images ($M = 0.46$, $SD = 0.14$). There was no significant interaction between condition and food image energy density $F(1, 42) = 0.79$, $p = 0.38$, and no significant main effect between conditions $F(1, 42) = 1.02$, $p = 0.32$.

Gaze Duration Bias

Two 2 (condition: mindful eating, control) × 2 (food image energy density: LED, HED) mixed design ANOVAs were carried out, with the condition being a between subjects factor and food image energy density being a repeated measures factor to explore average fixation duration and total fixation duration. For average fixation duration, there was no significant interaction between condition and food image energy density $F(1, 42) = 2.79$, $p = 0.10$, no main effect for food image energy density $F(1, 42) = 0.34$, $p = 0.56$, and no main effect between conditions $F(1, 42) = 1.81$, $p = 0.19$ (see Table 7). For total fixation duration, there was no significant interaction between condition and food image energy density $F(1, 42) = 1.73$, $p = 0.20$, no main effect between conditions $F(1, 42) = 0.70$, $p = 0.41$, but a main effect for food image density was found $F(1, 42) = 5.54$, $p = 0.02$, with participants displaying a greater total fixation duration towards HED food images ($M = 0.58$, $SD = 0.12$) compared to LED food images ($M = 0.54$, $SD = 0.09$).

Table 6 Pre- and post-measures of SMS between mindfulness and control conditions

	M (*SD*)—mindfulness (*n* = 22)	*M* (*SD*)—control (*n* = 22)
Pre	63.14 (17.02)	67.45 (15.39)
Post	75.14 (13.32)	68.27 (17.29)

M and *SD* are used to represent mean and standard deviation, respectively

Table 7 Attention bias measures of participants between mindfulness and control conditions

	M (SD)—mindfulness (*n* = 22)	*M* (SD)—control (*n* = 22)
Gaze direction bias		
LED	.47 (.13)	.46 (.15)
HED	.55 (.17)	.49 (.14)
Gaze duration		
Average fixation time (ms)		
LED food	216.37 (80.09)	198.64 (67.35)
HED food	215.00 (91.01)	198.64 (75.86)
LED non-food	198.18 (59.25)	182.73 (67.41)
HED non-food	208.64 (67.77)	175.01 (58.69)
Average fixation bias		
LED	.52 (.03)	.52 (.04)
HED	.50 (.03)	.53 (.04)
Total fixation time (ms)		
LED food	10,295.00 (6190. 80)	8687.98 (6350.36)
HED food	10,390.43 (6284.77)	9168.46 (7338.23)
LED non-food	8580.60 (4633.06)	6897.52 (5164.94)
HED non-food	8263.97 (4510.60)	5770.46 (4421.28)
Total fixation bias		
LED	.54 (.09)	.54 (.09)
HED	.56 (.12)	.60 (.12)

M and *SD* are used to represent mean and standard deviation, respectively

LED low energy density, *HED* high energy density

Exploratory Analyses: Associations Between Attentional Measures, Hunger and BMI

Pearson's correlations between attentional measures, hunger and BMI found a moderate significant and positive association between BMI and average fixation bias for HED food cues, $r = 0.35$, $p = 0.02$.

Discussion

The findings from study 2 showed that participants who used the MCD improved significantly more on their state mindfulness than those in the control condition. Further, in support of the hypotheses, the results from the eye-movement data demonstrated that all participants exhibited a greater initial attentional bias towards HED food images than LED food images. Contrary to the hypotheses, the findings indicated no significant differences in the maintenance of attentional biases towards food cues between participants in the mindful eating condition and those in the control condition. Participants' hunger, BMI, and fat and sugar consumption displayed no significant effect on the findings.

The increase in state mindfulness scores after using the MCD is consistent with previous findings, which found the MCD to successfully induce mindfulness both longitudinally and within experimental settings (Hussein et al., 2017; Mantzios & Wilson, 2014). The results indicating that mindful eating did not affect the maintenance of attentional bias towards food cues is surprising given that previous findings have concluded mindful eating to be a prominent factor in promoting healthier eating behaviours (Hussain et al., 2021a, 2021b; Mantzios et al., 2019, 2020).

General Discussion

Across two studies, the effect of mindfulness and mindful eating on attentional biases towards food cues was explored. In study 1, those who were exposed to mindfulness meditation had greater attention duration towards LED food images, whilst those in the control condition exhibited greater attention duration towards HED food images. In study 2, there were no significant differences in maintenance of attention toward food cues between participants exposed to a mindful-eating specific tool (i.e. MCD) and those in a control condition, which was a finding that did not correspond to previous research.

Comparing attentional biases towards food cues between a mindful eating practice condition and a control condition, which was not exposed to any food related material may provide a potential explanation for the non-significant findings. Although it is common to use non-food related materials as a control stimulus in eating behaviour research (e.g. Dutt et al., 2019; Mantzios et al., 2020; Marchiori & Papies, 2014, Robinson et al., 2014), the difference between reading the MCD and reading materials related to either healthy foods, unhealthy foods or even a neutral food article would have been beneficial in further understanding attentional biases towards food cues. Previous research suggested that attentional biases are observed through task relevant objects (Beck & Kastner, 2009; Hickey et al., 2010). For example, Kumar et al. (2016) found food related objects increased visual attention towards food cues, whereby merely thinking about food modulated the extent to which attention was captured, and holding specific information caused attention to be automatically drawn towards food stimuli (Higgs et al., 2015; Higgs et al., 2012; Rutters et al., 2015) . Similarly, Werthermann et al. (2014) found manipulating attentional bias for food cues increased cravings and food intake, suggesting a link between attention for food and food intake. Such evidence appears to indicate that attentional biases towards food stimuli can be created when one is exposed or primed to food related content (in the case of the present study, the MCD). However, as the present findings suggested no significant differences in attentional biases towards food cues between the mindfulness and control condition, it could be suggested that exposure to food related content whilst being mindful may be as effective as exposure to non-food stimuli in enabling people to be less biased towards food cues and ultimately consume less. Future research should also use a control condition exposed to a food related article, and explore any potential effects or differences in attentional biases towards food cues.

Although hunger, BMI (study 1, 2) and fat and sugar consumption (study 1) did not appear to have any impact on the current findings, other eating behaviours could have potentially contributed towards the difference in findings between study 1 and study 2. For example, research has suggested mindfulness is an element that can assist with problematic eating behaviours, such as emotional, external, and restraint eating (Alberts et al., 2012; Lattimore et al., 2011, 2020; Ouwens et al., 2015). Further evidence on eating behaviours has indicated greater attentional biases towards food cues amongst those who are high emotional and external eaters (Brignell et al., 2009; Hou et al., 2011; Hummel et al., 2018; Nijs et al., 2009), and mixed findings amongst restraint eaters, with some evidence suggesting a greater attentional bias towards HED foods, and others showing no significant differences (Hollit et al., 2010; Forestell et al., 2012; Werthmann et al., 2013). Therefore, exploring the effects of eating behaviours (i.e. emotional, external and restraint) on brief mindfulness and/or mindful eating training and attention biases towards food cues may be beneficial for any future research.

Similarly, both studies did not include a measure of motivation to either eat healthy or lose weight, which could have had important moderation implications. For example, the effects of mindfulness practice on attentional biases may only be apparent amongst those who are motivated to eat healthy or lose weight, as they may be motivated to regulate their attention away from HED foods to limit their desire for such foods. In a recent study, it was found reflective motivation for limiting calorie intake moderated the selection of caloric items, with less motivation being association with higher calorie selection, and greater motivation being associated with choosing fewer calories (Tapper et al., 2022). Therefore, future research may benefit from including a measure of motivation to eat healthy or lose weight to explore its potential effect.

The duration of the stimuli presentation is another factor that should also be considered when interpreting the findings. The pictorial stimuli in study 1 and study 2 was presented for 2000 ms, and whilst many researchers have indicated that stimuli presented for 1000 ms or longer is suitable to investigate maintained attention (Castellanos et al., 2009; Doolan et al., 2014), others have conflicting methodological interpretations, with suggestions that 500 ms of stimuli presentation is an appropriate measure of maintained attention (Field & Cox, 2008; Koster et al., 2005). The difference of interpretation has also led to conflicting conclusions, with some researchers finding significant main effects between weight groups on their attentional biases towards food cues using stimuli presented for 500 ms (Nijs, Muris, et al., 2010), and others finding no significant differences between weight groups and their attention biases towards food cues after a stimuli presentation of 2000 ms (Castellanos et al., 2009).

Furthermore, study 1 and study 2 also used two different eye-tracking methodology designs, whereby study 1 used a HED vs LED food cue pictorial stimuli (e.g. Hummel et al., 2018), and study 2 used a HED food cue vs control cue and LED food cue vs control cue pictorial stimuli (e.g. Castellanos et al., 2009). It has been suggested that studies using more comprehensive eye-tracking methodologies, for example, by employing a visual probe task (an indirect measure of attention) to explore attentional measures towards food cues found different results despite both methods being used within the same participant pool (e.g. Doolan et al., 2014). Therefore, suggesting that length of stimuli presentation and even the type of methodology used to measure attention towards food cues can affect the results obtained, and future studies are indeed required to identify the most accurate measure of attentional biases towards food cues, or even run two durations of the same paradigm when using mindfulness.

Limitations and Future Directions

There are several limitations and potential avenues for future research that have been identified. First, both studies were conducted in a controlled laboratory setting whereby participants were facing a computer with a screen-based eye-tracking device, suggesting a lack of ecological validity. Future research should consider using methodologies that resemble more naturalistic settings. This could potentially be achieved through participants traversing a real-life setting whilst wearing an eye-tracking apparatus (Graham et al., 2012) or even using the concept of virtual reality, whereby participants perform shopping tasks or are simply presented with advertisements of foods whilst measuring their visual attention (Folkvord et al., 2016; Melendrez-Ruiz et al., 2021).

Additionally, the present studies predominantly recruited healthy female undergraduates, and therefore, the findings may not hold for different populations. Research has shown differences in visual attention toward food cues between both male and female healthy weight and overweight or participants with obesity (Castellanos et al., 2009; Doolan et al., 2014; Nijs, Muris, et al., 2010). Future research should explore the effectiveness of mindfulness and visual attention on food cues in all healthy weight and overweight or obese mixed-gender populations.

Furthermore, the sample size used in both studies was rather small, which could have increased the chances of spurious findings (i.e. type II error), decreasing the power of both studies (Faber & Fonseca, 2014). Using a larger sample would increase the power of the studies to detect significant effects, and as such, future research should calculate sample sizes prior to data collection to ensure that studies are adequately powered to detect accurate effects. Moreover, using an adequate sample size would also allow future research to explore the potential mediation of state mindfulness and attentional measures (Fritz & MacKinnon, 2007).

Another limitation that needs to be acknowledged regarding study 2 is the slight difference in hunger amongst participants across the two conditions. Previous research has found that hunger can affect attentional biases for food cues, with higher levels of hunger predicting greater attentional bias towards both HED and LED food cues (Folkvord et al., 2020; Tapper et al., 2010). To minimise the risk of such imbalance between conditions, future research should apply stratified randomisation, as well as recruit a larger sample size.

Finally, future research could explore the long-term effects of using mindfulness meditation or the MCD on attentional biases towards food cues. Previous research has displayed the long-term benefits of mindfulness meditation and using the MCD on weight loss and weight regulation (Mantzios & Wilson, 2014). Thus, priming participants with the MCD or practicing mindfulness meditation over a longer period of time could also potentially improve their attentional biases towards food cues, and in turn, lead to weight loss and weight regulation.

Conclusion

In conclusion, study 1 found mindfulness meditation resulted in significantly greater attention duration towards LED foods and the control condition exhibited greater attention duration towards HED food images. Whilst in study 2, the maintenance of attentional bias towards food cues did not appear to be significantly influenced by the MCD. Given the abundance of HED food cues within the contemporary environment, future research should explore the long-term effects of mindfulness and mindful eating on attentional biases towards food cues and whether this can translate into weight regulation.

Author Contribution MH designed the study, collected data, conducted data analyses, and wrote the manuscript. MU collected data, and JW, NS, HE, RK, and MM supported the study and reviewed the manuscript. All authors gave their final approval of the manuscript.

Data Availability Data and material are available on request from the corresponding author [MH].

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

Ethical Approval The study was approved by the ethical review board of the University and was in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments. This article does not contain any studies with animals.

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Consent for Publications Informed consent for the publication of this study was obtained from all individual participants included in the study.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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