A comparison of meal-related appetite, food reward and eating behaviour traits in people with and without spinal cord injury

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Abstract

Persons with a spinal cord injury (SCI) are at a heightened risk of obesity. However, little is known about the effect of SCI on factors that influence energy intake. This study compared measures of food reward, eating behaviour traits, and appetite perceptions between adults with and without SCI. Twenty wheelchair dependent persons with chronic (>1 year) SCI (C1-T12) and twenty non-SCI individuals matched for BMI, age and sex participated. Following a familiarisation visit, participants consumed a breakfast meal, normalised for resting metabolic rate (RMR), and provided subjective appetite perceptions every 30 min for 4 h. Subsequently, energy intake was determined via an *ad libitum* lunch meal. Explicit liking, explicit wanting, implicit wanting and relative preference were assessed in a hungry and fed state via the Leeds Food Preference Questionnaire prior to and following the lunch meal. Eating behaviour traits were assessed via the Adult Eating Behaviour Questionnaire, Control of Eating Questionnaire, Reasons Individuals Stop Eating Questionnaire, and Three Factor Eating Questionnaire Revised 18-item version. Sweet appeal bias was greater for explicit liking, explicit wanting, and relative preference in the group with SCI compared to the non-SCI group ($p \leq 0.024$). The group with SCI also reported higher levels of cognitive restraint and satiety responsiveness ($p \leq 0.029$). No group differences in postprandial appetite perceptions ($p \geq 0.690$) or energy intake relative to RMR were seen ($p = 0.358$). However, the group with SCI demonstrated a trend toward a lower absolute energy intake ($p = 0.063$). In conclusion, food reward for sweet foods was greater in the group with SCI. Further, our findings suggest that acute appetite perceptions, including satiety profiles, are not different between persons with and without SCI.

Keywords: paraplegia; food preference; satiety; energy intake.

Abbreviations: BMI, body mass index; LFPQ, Leeds Food Preference Questionnaire; RMR, resting metabolic rate; SCI, spinal cord injury; VAS, visual analogue scale.

1. Introduction

A spinal cord injury (SCI) is a medical condition wherein damage to the spinal cord impairs motor, sensory and autonomic function below the level of injury. Paralysis and increased reliance on a wheelchair for locomotion results in a substantial reduction in physical activity energy expenditure. Further, a decrease in resting metabolic rate (RMR), due to the loss of metabolically active tissue, such as skeletal muscle mass, prompt substantial reductions in total daily energy expenditure, predisposing this population to obesity (Gater, 2007; Gorgey et al., 2014). Research in non-SCI populations demonstrates that people with low daily energy expenditure exhibit signs of impaired appetite regulation, with difficulty matching daily energy intake and expenditure (Hopkins & Blundell, 2016). Given physical limitations, it is possible that appetite may become desensitised in people with SCI; however, few studies have investigated this issue.

Appetite and eating behaviour are influenced by interacting physiological and psychological factors (Hopkins et al., 2016). Specifically, a network of appetite-related hormones is known to modulate feelings of hunger, satiation, and satiety; with acute (meal-to-meal) and chronic influences. In the context of SCI, evidence suggests that circulating concentrations of acylated ghrelin, peptide YY, and glucagon-like peptide-1 are not different between persons with or without SCI, in a fasted state (Fenton et al., 2021; Saltzstein et al., 1995; Wang et al., 2005). In our recent comparative study, we also observed no differences between groups with and without SCI in the postprandial trends of these hormones following an isocaloric preload over 2.5 h (Fenton et al., 2021). However, visual analogue scales (VAS) revealed accentuated satiety responses in the group with SCI in the first hour postprandially. This outcome may reflect undefined population differences in gastrointestinal physiology, and/or meal-related sensory perceptions / cognitive processes. Alternatively, in our study, the *relatively* larger meal size consumed by those with SCI may be explanative. Further experiments are needed to confirm whether SCI is associated with enhanced satiety responsiveness and to explore the potential contribution of psychological mediators.

Within the discipline of biological psychology, 'food reward' considers the hedonic aspects of appetite and eating behaviour. Food reward is underpinned by momentary "liking", the subjective pleasure of a food, and "wanting", the motivational value of a food (Finlayson & Dalton, 2012; Oustric et al., 2020), and is commonly assessed using the Leeds Food Preference Questionnaire (LFPQ) (Finlayson et al., 2007). Evidence suggests that people who are inactive and living with overweight/obesity often exhibit greater liking and wanting scores for energy-dense foods, compared to active individuals with a healthy body weight (Finlayson & Dalton, 2012; Horner et al., 2016; Oustric et al., 2018). These hedonic characteristics have been shown to encourage overconsumption, thus amplifying the rate of weight gain (Beaulieu et al., 2018). Given that excess adiposity and physical inactivity are common in people with

SCI (Spungen et al., 2003; van den Berg-Emons et al., 2010), it is possible that disrupted food reward is apparent in this population. However, this possibility has not been investigated.

Other psychological factors, such as eating behaviour traits, influence food choice and portion size selection. For example, positive associations between 'food approach' traits, such as uncontrolled eating and appetite-related disinhibition, have been reported in persons with higher adiposity and lower levels of physical activity (Myers et al., 2017; Shook et al., 2015). Likewise, 'food avoidance' traits, such as satiety responsiveness and slowness in eating, are associated with a lower body mass index (BMI) (Mallan et al., 2017). Although non-ambulatory persons with SCI often exhibit low physical activity energy expenditure and excess adiposity SCI (Spungen et al., 2003; van den Berg-Emons et al., 2010), a quantitative assessment of eating behaviour traits has not been conducted in the general SCI population.

Based on the aforementioned evidence, this study sought to compare meal-related appetite perceptions, measures of satiety profile, and food reward responses between persons with and without SCI. Potential differences in eating behaviour traits were also examined. We hypothesised that no group differences in meal-related perceptions of hunger, satiation, and satiety would be apparent when the energy content of a test meal was scaled to individuals' daily energy requirements. Moreover, people with SCI would display greater motivation and preference for energy dense foods (sweet and fatty) than those without SCI. Finally, persons with SCI would exhibit more 'food approach' eating behaviour traits, and fewer 'food avoidance traits compared to the non-SCI group.

2. Methods

2.1. Ethical approval and participants

Following approval from the Loughborough University Ethics Review Sub-Committee (project ID: 5574), 20 participants with chronic (>1-year post-injury) SCI and 20 age-, sex- and BMI-matched non-SCI individuals provided written informed consent to participate. Inclusion criteria were non-smoking men and women, aged 18-64 years, metabolically, weight stable (body mass ± 3 kg for the past 3 months), and habitual breakfast and lunch consumers. Trained athletes, persons following vegan or vegetarian diets, and those with allergies, intolerances, or a dislike to any of the foods included in the study were excluded. All female participants reported being eumenorrheic and not pregnant. Classification of SCI was self-reported, with motor complete SCI defined as a complete loss of motor function below the lesion level, and incomplete SCI defined as partial loss of motor and sensory function. All participants with incomplete SCI were wheelchair dependent for daily ambulation. Characteristics of the study participants are shown in Table 1. Given the exploratory nature of this study, a formal power calculation was not conducted. Instead, sample size was determined from previous studies using similar study designs (Beaulieu et al., 2020; Horner et al., 2016).

2.2. Pre-assessment and familiarisation

Participants attended the laboratory on two occasions for a familiarisation visit and the experimental trial. In the familiarisation visit body mass of the participants with SCI was measured using a wheelchair weighing scale (DETECTO 6550, Missouri, USA). Height and SCI-related information (time since injury, injury level and injury completeness) was self-reported. Supine waist and hip circumferences were measured using an inelastic polyfibre tape measure (Hokanson, Washington, USA) for all participants. In the non-SCI group, measures of stature and body mass were performed using a portable stadiometer and digital scale (Seca Ltd, Hamburg, Germany). All measures were made in duplicate and to the nearest 0.1 cm or 0.1 kg. Participants were then familiarised with the study protocol, the LFPQ, the 100 mm visual analogue scale(s) (VAS) used for subjective appetite measures (Flint et al., 2000), and the *ad libitum* lunch meal.

Skinfold thickness was measured on the biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, front thigh and medial calf on the right-hand side of the body in accordance with the International Society for the Advancement of Kinanthropometry (ISAK), using Harpenden skinfold callipers (HaB Direct, Southam, UK) (Norton, 2019), as previously used by our group (Goosey-Tolfrey et al., 2021; Sutton et al., 2009).To permit group comparisons, for all participants, skinfolds were measured whilst sat in a chair/wheelchair.

2.3. Study design

Participants were instructed to abstain from strenuous exercise, caffeine, and alcohol in the 24 h prior to arriving at the laboratory for the main trial and were asked to stop eating and drinking (other than water) from 22:00. Participants arrived at 08:00 for the experimental trial (Figure 1) and were asked to rest on a bed in a supine position whilst RMR was measured. Participants were then provided with breakfast. Appetite rating VAS were completed immediately before and after breakfast, and every 0.5 h thereafter for 4 h. During this period, participants were asked to remain seated in a quiet room and were permitted to undertake sedentary tasks. Participants were also asked to complete several questionnaires related to their eating behaviour during this time. At 2 h post-breakfast, participants completed the hypothetical expected satiety task. After 4 h, participants underwent the momentary expected satiety task, the ideal portion size task, and the pre-meal LFPQ. They were then asked to complete a VAS for perceived appetite and consume the *ad libitum* lunch meal. This was succeeded by the post-meal LFPQ and a final VAS.

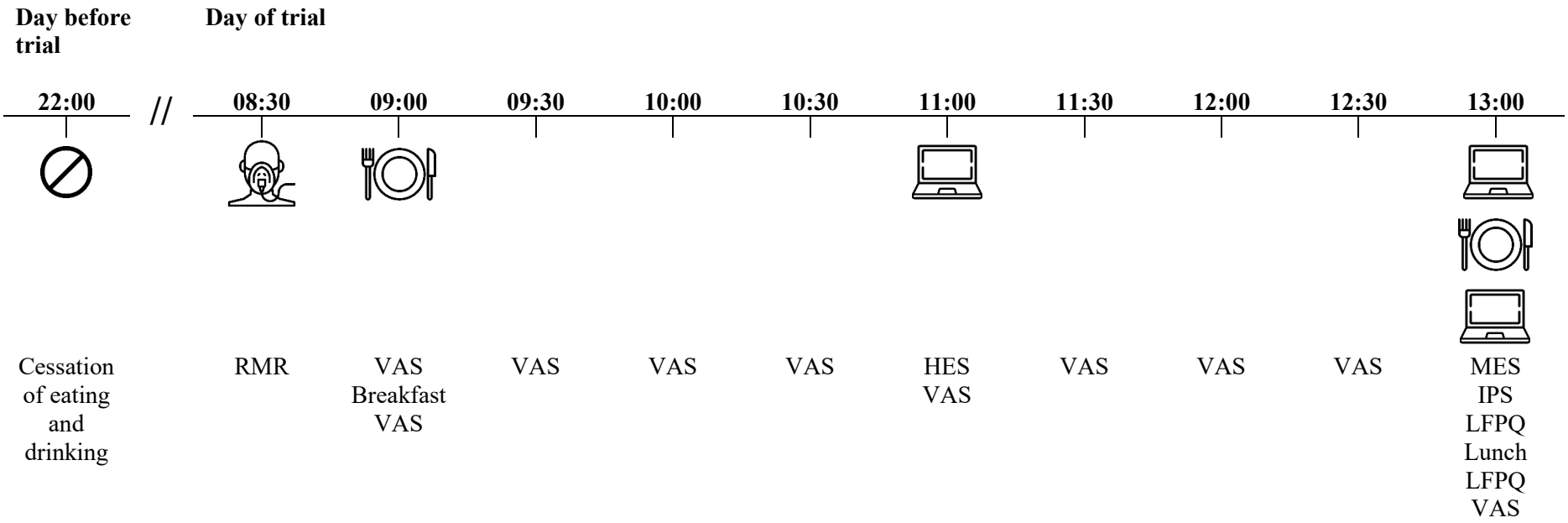


Figure 1. Schematic illustration of the experiment protocol (HES, hypothetical expected satiety; IPS, ideal portion size; LFPQ, Leeds food preference questionnaire; RMR, resting metabolic rate; VAS, visual analogue scale).

2.4. Study foods

Breakfast consisted of a ground oat porridge meal (Ready Brek, UK), whole milk and honey (56% carbohydrate, 28% fat, 14% protein), with an energy content calculated relative to the estimated daily energy requirements of each participant (20% of participants' estimated energy requirements) (Clayton et al., 2016). Given the sedentary nature of the protocol, estimated energy requirements were determined by multiplying RMR by a sedentary activity factor of 1.2 (Collins et al., 2010; Jetté et al., 1990; Nightingale et al., 2017).

The lunch meal consisted of cheese (medium cheddar), passata, fusilli pasta and olive oil (all Tesco, UK). Participants were presented with the pasta in a large bowl, served at room temperature, and in excess of predicted consumption (6188 kJ, 44% carbohydrate, 41% fat, 14% protein) and were instructed to eat until comfortably full. The meals were consumed in isolation (other than the participants with SCI that required assistance) and the use of electronic devices during the eating period was prohibited (Braude & Stevenson, 2014). The mass of food consumed was determined by subtracting the mass of food remaining from that initially presented. Participants were offered a 150 ml glass of water with the study foods and were told to drink *ad libitum* throughout the day.

2.5. Leeds Food Preference Questionnaire

The LFPQ is a validated laptop-based questionnaire that assesses different components of food preference and reward (Finlayson et al., 2007). A detailed description of how the LFPQ is conducted and analysed has been published (Dalton & Finlayson, 2014). To summarise, sixteen food items from four different categories (high-fat savoury, high-fat sweet, low-fat savoury, low-fat sweet) were utilised in the questionnaire. Explicit liking and explicit wanting were assessed by asking participants how much they would 'like to taste', and 'want to eat', respectively, some of the food presented in front of them at that moment in time using a 100 mm VAS. A score of 0 represented "Not at all", and a score of 100 represented "Extremely". Relative preference was assessed by presenting participants with two foods and asking them to choose which food they 'most want to eat now'. Scores for relative preferences were ascertained by the mean frequency of selection for each food type. Implicit wanting was determined by the number of times a certain category of food was and was not chosen, as well as the time taken to choose between the two foods. 'Fat appeal bias' and 'sweet appeal bias' scores were determined by deducting the low-fat scores from the high-fat scores, and the savoury scores from the sweet scores, respectively.

2.6. Eating behaviour traits

Four eating behaviour trait questionnaires were implemented in this study. These included the Adult Eating Behaviour Questionnaire (Hunot et al., 2016), the Control of Eating Questionnaire (Dalton et

al., 2015), the Reasons Individuals Stop Eating Questionnaire (Cunningham et al., 2021), and the Three-Factor Eating Questionnaire – Revised 18-item version (de Lauzon et al., 2004).

2.7. Appetite perceptions

Ratings of perceived hunger, satisfaction, fullness, and prospective food consumption were assessed using a 100 mm VAS (Flint et al., 2000). Pleasantness and satisfaction of the breakfast and lunch meals were also rated immediately after participants had finished eating. Each scale defined 0 mm as "not at all" and 100 mm as "totally / a lot / very", and participants were asked to put a vertical line at the point corresponding to their appetite at that point in time.

2.8. Expected satiety and ideal portion size

Expected satiety measures and ideal portion size were determined using the method of adjustment, which has been described previously (Brunstrom & Rogers, 2009; McLeod et al., 2022). To assess hypothetical expected satiety participants were presented with a laptop which displayed a 'standard' food (1255 kJ portion of plain pilau rice) and one of six 'comparison' foods (porridge, granola, chicken chow mein, cheese and tomato pasta, crisps, or chocolate). Participants were instructed to change the portion size of the comparison foods so that both foods would stave off hunger to the same extent. For momentary expected satiety and ideal portion size, participants were presented with an image of cheese and tomato pasta that could be adjutsed for portion size. Participants were asked to select a portion that would stop them feeling hungry until their next meal in 5 hours' time, and a portion that they would eat right now if it was the only food available until their next meal in 5 hours' time, respectively. Portion sizes for each comparison food ranged from 0-4184 kJ.

2.9. Energy expenditure and physical activity status

Resting metabolic rate was determined using a mobile spiroergometric device (Metamax 3B, Cortex, Germany) and MetaSoft Studio software (Cortex, Germany) in accordance with best practise guidelines (Compher et al., 2006). Participants lay in a supine position for 30 min whilst the device measured oxygen consumption ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$) and the volume of expired air on a second-by-second basis, with the last 10 min used for analysis. Carbohydrate and fat oxidation were determined from the volume of $\dot{V}O_2$ and $\dot{V}CO_2$, with the assumption that protein oxidation at rest was negligible (Frayn, 1983). Energy expenditure was then calculated using a caloric equivalent for carbohydrate and fat oxidation (Ferrannini, 1988) and averaged over the last 10 min. This value was extrapolated over 24 h to determine RMR. Physical activity status was assessed using the Leisure Time Physical Activity Questionnaire for People with Spinal Cord Injury (Ginis et al., 2012), and the International Physical Activity Questionnaire – Short Form (Craig et al., 2003) for the non-SCI group.

2.10. Statistical analysis

Data were analysed using the Statistical Package for Social Sciences (SPSS) software version 27 for Windows (IBM Corporation, USA). Preceding analysis, tests of normality and homogeneity were run to assess parametric assumptions. For the LFPQ data, two-way mixed ANOVAs were used to determine group (SCI vs. non-SCI) time (pre- vs. post-lunch) effects for relative preference, implicit wanting, explicit liking and explicit wanting. A two-way mixed ANOVA was also used to explore the interaction between momentary expected satiety and ideal portion size, as well as between group effects. For hypothetical expected satiety, a repeated measures ANOVA was used to explore the effect of group and food as fixed factors. Similarly, differences in appetite perceptions over time were assessed using repeated measures ANOVAs with group and time. Post-hoc Bonferroni corrected pairwise comparisons were conducted for all general linear models when a main effect was detected. Given the anticipated differences in lean mass between groups, absolute energy intake was also analysed relative to RMR ((energy intake / RMR) * 100). Independent samples t-tests and Mann-Whitney U tests were used to compare all other parametric and non-parametric data between groups, respectively. Test-specific effect sizes (Cohen's *d*) were calculated to supplement each parametric statistical test, with large, moderate, small, and trivial effect sizes defined as 0.8, 0.5, 0.2, and < 0.2, respectively (Cohen, 1988). For mixed ANOVAs, effect sizes were determined using partial eta squared (η_p^2), with 0.14, 0.06 and 0.01 defined as large, medium, and small effect sizes, respectively. For non-parametric data, effect sizes were calculated using Rosenthal's *r* (Rosenthal, 2011), with large, medium, and small effects classified as 0.5, 0.3, and 0.1 respectively. Mean ± SD was reported for all parametric data, whereas the median (IQR) was reported for non-parametric data. Statistical significance was defined as $p < 0.05$.

3. Results

3.1. Demographic information

Demographic data for the 40 participants are reported in Table 1. There were no differences in age, body mass, height, BMI, or supine hip circumference between the SCI and non-SCI groups ($p \geq 0.092$; $d \leq 0.56$). However, supine waist circumference ($t(38) = -2.465$; p 0.018; $d = 0.78$) and supine waist-to-hip ratio ($t(38) = 2.437$; $p = 0.020$; $d = 0.77$) were greater in the group with SCI, with ΣSF8 approaching between-group significance ($t(38) = 1.948$; $p = 0.059$; $d = 0.62$). RMR was also lower in the group with SCI compared to the non-SCI group ($t(38) = -2.188$; $p = 0.035$; $d = 0.69$).

Table 1

Participant demographic information.

Group	SCI, n = 20	Non-SCI, n = 20
Sex	Male, n = 14	Male, n = 14
	Female, n = 6	Female, n = 6
Age (yr)	37 (28-49)	30 (26-48)
Body mass (kg)	79.2 ± 17.4	73.8 ± 14.5
Height (cm)	176.0 ± 0.1	173.0 ± 0.1
BMI ($kg.m^{-2}$)	25.5 ± 5.2	24.6 ± 3.2
Resting metabolic rate ($kJ.day^{-1}$)	6736 ± 1084*	7719 ± 1703
Hip circumference - supine (cm)	104.5 ± 16.0	97.8 ± 5.6
Waist circumference - supine (cm)	92.7 ± 15.3 *	82.7 ± 9.5
Waist-to-hip ratio - supine	0.91 ± 0.1 *	0.84 ± 0.1
Sum of eight skinfold sites (mm)	152.8 ± 56.4	121.7 ± 43.6
Time spent sitting ($min.week^{-1}$) +		3465 (2940-4200)
Mild exercise / walking ($min.week^{-1}$) +	140 (23-360)	225 (203-420)
Moderate exercise ($min.week^{-1}$) +	120 (30-180)	120 (60-203)
Heavy / vigorous exercise ($min.week^{-1}$) +	99 ± 105	155 ± 135
Injury duration (yr)	11.5 ± 9.9	
Injury category (AIS)	A, n = 7	
	B, n = 4	
	C, n = 9	
Injury level	Paraplegia (T2-T12), n = 8	
	Tetraplegia (C1-C7), n = 12	

Mean ± SD; Median (IQR).

* Significant difference between groups ($p < 0.05$); + Different questionnaires were used to assess physical activity status in these groups, meaning results were not directly comparable.

AIS, American Spinal Injury Association Impairment Scale; BMI, body mass index; C, cervical; SCI, spinal cord injury; T, thoracic.

3.2. Food preference and reward

For sweet appeal bias scores, there were significant group effects for explicit liking, explicit wanting, and relative preference ($p \leq 0.024$; $\eta_p^2 \geq 0.127$), with implicit wanting approaching significance ($p = 0.059$; $\eta_p^2 = 0.091$) (Table 2). Both groups demonstrated a shift in sweet appeal bias for explicit liking, explicit wanting, implicit wanting and relative preference from pre- to post-meal which inferred a stronger bias for sweet foods following the lunch meal ($p < 0.001$; $\eta_p^2 \geq 0.569$). However, no interaction

effects were found for any sweet appeal bias metric ($p \geq 0.501$; $\eta_p^2 \leq 0.01$). For fat appeal bias scores, explicit liking, explicit wanting, implicit wanting and relative preference were not different between pre-lunch and post-lunch time points ($p \geq 0.127$; $\eta_p^2 \leq 0.060$). Similarly, no group or interaction effects were seen for these any of these metrics ($p \geq 0.181$; $\eta_p^2 \leq 0.047$).

Table 2

Measures of explicit liking, explicit wanting, implicit wanting and relative preference assessed immediately before and after an *ad libitum* lunch meal in persons with a spinal cord injury (SCI; n = 20) and non-SCI (n = 20) (no interaction main effects were found ($p \geq 0.501$; $\eta_p^2 \leq 0.01$) and data were omitted for clarity).

	Pre-lunch		**Post-lunch**		**Group effect**			**Time effect**		
	SCI	**non-SCI**	**SCI**	**non-SCI**	$F_{(1,38)}$	p	η_p^2	$F_{(1,38)}$	p	η_p^2
Explicit liking										
Sweet appeal bias	1 ± 18	-17 ± 22	35 ± 22	23 ± 20	14.247	0.001*	0.451	50.129	< 0.001*	0.569
Fat appeal bias	4 ± 12	4 ± 9	5 ± 11	4 ± 15	0.005	0.945	<0.001	0.026	0.872	0.001
Explicit wanting										
Sweet appeal bias	-3 ± 20	-20 ± 20	32 ± 24	22 ± 15	12.743	0.001*	0.251	57.674	< 0.001*	0.603
Fat appeal bias	3 ± 13	3 ± 12	5 ± 8	3 ± 12	0.14	0.710	0.004	0.208	0.651	0.005
Implicit wanting										
Sweet appeal bias	-14 ± 47	-32 ± 35	63 ± 26	48 ± 32	3.799	0.059	0.091	104.692	< 0.001*	0.734
Fat appeal bias	14 ± 30	6 ± 27	16 ± 17	12 ± 19	1.066	0.308	0.027	0.68	0.415	0.018
Relative preference										
Sweet appeal bias	-5 ± 18	-13 ± 13	24 ± 10	17 ± 11	5.507	0.024*	0.127	112.414	< 0.001*	0.747
Fat appeal bias	5 ± 11	2 ± 10	7 ± 7	5 ± 8	1.855	0.181	0.047	2.429	0.127	0.060

Values are mean ± SD.

* Significant difference ($p < 0.05$).

3.3. Ratings of perceived appetite and palatability

There were no differences between groups in pre-breakfast levels of hunger, satisfaction, fullness, or prospective future consumption ($p \geq 0.300$; $d \leq 0.33$). Similarly, no group or group-by-time interaction effects were apparent for any of the appetite perceptions from 0-4 h post breakfast consumption ($p \geq 0.690$; $\eta_p^2 \leq 0.018$) (Figure 2). In contrast, an effect of time was detected for all appetite perceptions in the 0-4 h postprandial period (all $p < 0.001$ 0.; $\eta_p^2 \geq 0.692$). There was no group effect for how pleasant participants found the breakfast ($t(38) = -0.109$; $p = 0.914$; $d = 0.035$) or lunch ($t(38) = -0.649$; $p = 0.520$; $d = 0.207$) meals. Similarly, no difference in how satisfying participants perceived breakfast to be ($t(38) = -1.526$; $p = 0.135$; $d = 0.579$) was identified. Conversely, the group with SCI deemed the lunch meal to be less satisfying than participants in the non-SCI group ($t(38) = -2.461$; $p = 0.018$; $d = 0.778$).

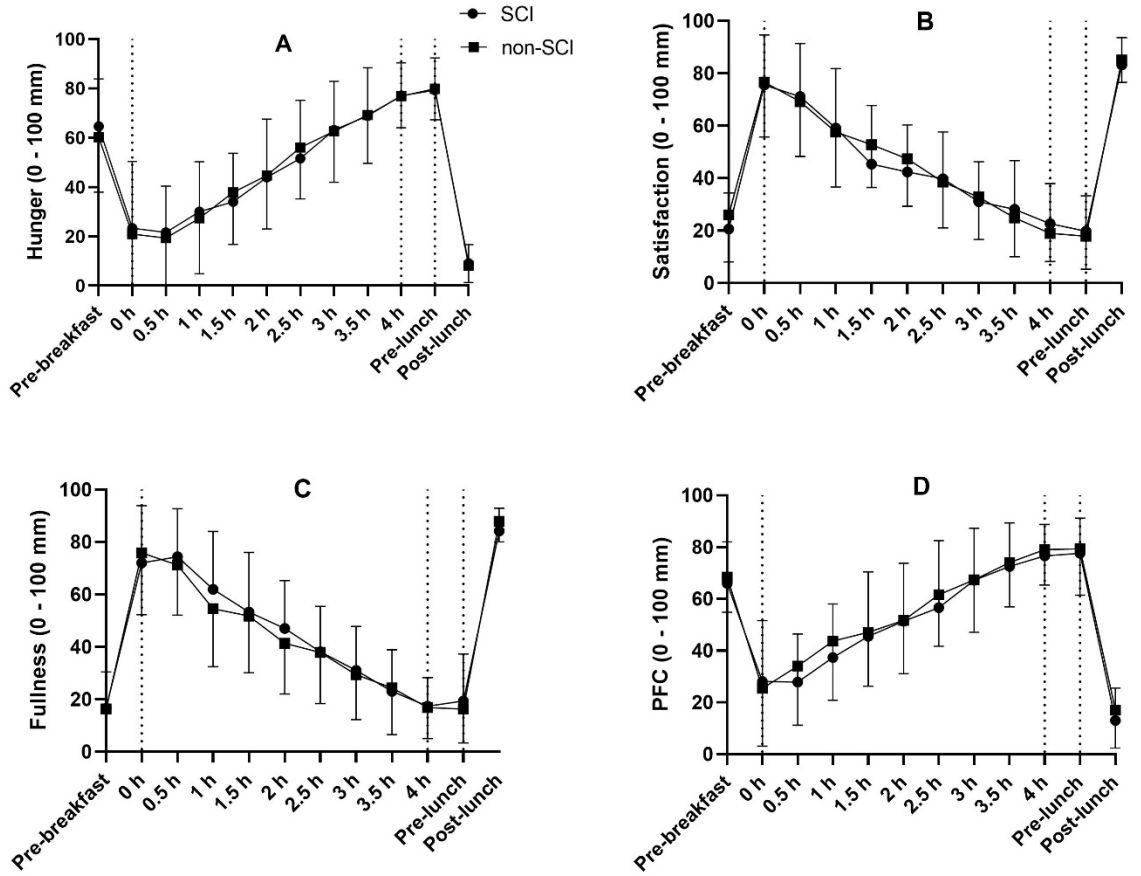


Figure 2. Perceptions of hunger (A, B) satisfaction (C, D), fullness, (E, F) and prospective future consumption (G, H) in persons with spinal cord injury (SCI) and non-SCI individuals. Data are mean ± SD (n = 20 in each group). Vertical dotted lines were added for visual aid of the four time points.

3.4. Energy intake

Energy intake at the breakfast meal was lower in the SCI, compared to the non-SCI group (t(38) = -2.188; p = 0.035; *d* = 0.69) (Figure 3A). Trends toward a lower absolute energy intake in the group with SCI were also seen at the *ad libitum* lunch meal (t(38) = -1.916; p = 0.063; *d* = 0.56) (Figure 3A). However, relative energy intake (energy intake scaled to RMR) (U =166; p = 0.358; *r* = 0.15) (Figure 3B) was not different between groups.

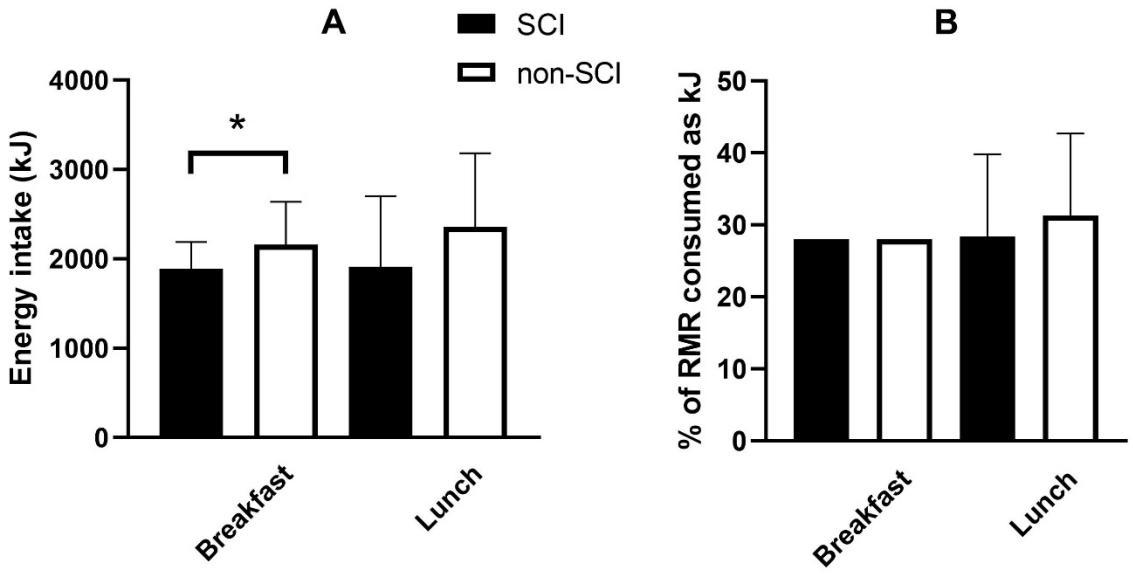


Figure 3. Breakfast and lunch energy intake (A), and energy intake as a percentage of RMR at the breakfast and lunch meal (B). Data are mean ± SD (n = 20 in each group). * Significant difference (p < 0.05).

3.5. Trait and state eating behaviour questionnaires

3.5.1. Adult Eating Behaviour Questionnaire

Satiety responsiveness was higher in the group with SCI, compared to the non-SCI group (t(38) = 2.266; p = 0.029; *d* = 0.72; Table 3). However, no significant group differences were found for slowness in eating (t(38) = 0.502; p = 0.618; *d* = 0.16), emotional under eating (t(38) = 1.195; p = 0.240; *d* = 0.38), food fussiness (t(38) = -5.02; p = 0.619; *d* = 0.16), food responsiveness (t(38) = 0.75; p = 0.458; *d* = 0.24), emotional overeating (t(38) = 0.869; p = 0.39; *d* = 0.25), hunger (t(38) = 0.234; p = 0.816; *d* = 0.07), or enjoyment of food (U = 196.5; p = 0.922; *r* = 0.02).

3.5.2. Control of Eating Questionnaire

Craving for savoury foods was lower in the SCI group compared to the non-SCI group (t(38) = -2.975; p = 0.005; *d* = 0.94; Table 3). However, no significant group differences for craving control (t(38) = 1.03; p = 0.310; *d* = 0.33), positive mood (t(38) = 0.522; p = 0.605; *d* = 0.12) or craving for sweet foods (t(38) = -1.149; p = 0.258; *d* = 0.36) were found.

3.5.3. Reasons Individuals Stop Eating Questionnaire

Scores of decreased food appeal ($t(38) = 0.71$; $p = 0.482$; $d = 0.23$), physical satisfaction ($t(38) = -0.049$; $p = 0.962$; $d = 0.06$), planned amount ($U = 197.5$; $p = 0.946$; $r = 0.01$), self-consciousness ($U = 140$; $p = 0.101$; $r = 0.26$), and decreased priority of eating ($U = 176$; $p = 0.513$; $r = 0.10$) were not significantly different between the group with SCI and the non-SCI group (Table 3).

3.5.4. Three Factor Eating Questionnaire (R-18)

The group with SCI reported higher levels of cognitive restraint compared to the non-SCI group ($t(38) = 2.297$; $p = 0.027$; $d = 0.726$; Table 3), though no significant differences were detected when comparing uncontrolled eating ($t(38) = -0454$; $p = 0.652$; $d = 0.02$) or emotional eating ($U = 155$; $p = 0.216$; $r = 0.196$).

Table 3

Scores from different trait eating behaviour questionnaires in persons with and without a spinal cord injury (SCI).

	SCI (n=20)	Non-SCI (n=20)
Adult Eating Behaviour Questionnaire		
Food approach		
Slowness in eating	9.8 ± 4.1	9.2 ± 3.4
Emotional under-eating	14.6 ± 4.8	12.9 ± 4.5
Food fussiness	6.0 ± 3.4	6.5 ± 2.8
Satiety responsiveness	10.3 ± 3.2 *	8.2 ± 2.4
Food avoidance		
Food responsiveness	13.1 ± 3.2	12.4 ± 2.7
Emotional overeating	11.9 ± 5.0	10.7 ± 4.6
Hunger	15.1 ± 4.3	14.8 ± 3.8
Enjoyment of food	14.0 (12.0-15.0)	14.0 (12.3-15.0)
Control of Eating Questionnaire		
Craving control	68.5 ± 21.5	61.7 ± 20.0
Positive mood	70.8 ± 18.8	68.6 ± 16.8
Craving for savoury	34.4 ± 14.3 *	49.1 ± 16.8
Craving for sweet	33.3 ± 20.2	40.9 ± 21.6
Reasons Individuals Stop Eating Questionnaire		
Decreased food appeal	2.4 ± 0.8	2.2 ± 0.8
Physical satisfaction	4.4 ± 1.0	4.4 ± 1.3
Planned amount	4.3 (4.0-5.0)	4.4 (3.7-5.2)
Self-consciousness	1.9 (1.4-3.0)	1.4 (1.0-2.3)
Decreased priority of eating	2.0 (1.8-2.8)	2.0 (1.1-2.8)
Three Factor Eating Questionnaire - Revised 18-item version		
Uncontrolled eating	37.8 ± 20.3	37.4 ± 12.6
Cognitive restraint	49.1 ± 16.9 *	36.8 ± 16.9
Emotional eating	33.3 (13.9-41.7)	22.2 (2.8-33.3)

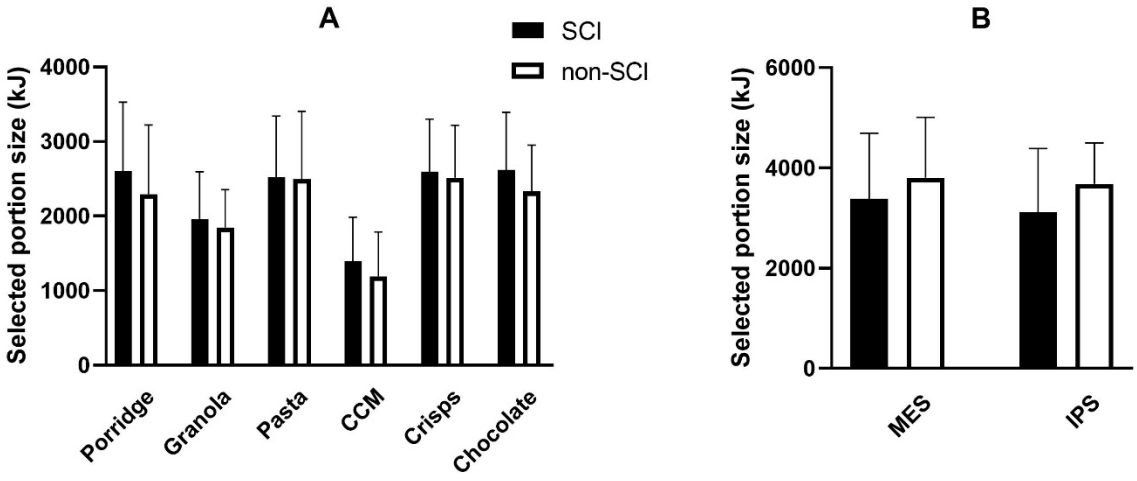
Mean ± SD; *Median (IQR).*

* Significant difference between groups ($p < 0.05$).

314

315 *3.6. Expected satiety and Ideal portion size*

316 For measures of hypothetical expected satiety, there was no effect of group ($F_{(1,38)} = 1.274$; $p = 0.266$;
317 $\eta_p^2 = 0.032$), and no interaction effect ($F_{(1,38)} = 0.346$; $p = 0.884$; $\eta_p^2 = 0.009$). However, a main effect
318 of food was present ($F_{(1,38)} = 26.894$; $p < 0.001$; $\eta_p^2 = 0.414$) (Figure 4A). In contrast, no main effect of
319 group ($F_{(1,38)} = 2.116$; $p = 0.154$; $\eta_p^2 = 0.054$), food ($F_{(1,38)} = 1.468$; $p = 0.233$; $\eta_p^2 = 0.038$), or interaction
320 effect ($F_{(1,38)} = 0.193$; $p = 0.663$; $\eta_p^2 = 0.005$) was found for ideal portion size and momentary expected
321 satiety (Figure 4B).



322

323 **Figure 4.** Hypothetical expected satiety assessments for six test foods (A), and momentary expected
324 satiety (MES) and ideal portion size (IPS) for cheese and tomato pasta (B) in persons with a spinal cord
325 injury (SCI) and non-SCI individuals. Data are mean ± SD (n = 20 in each group).

326 **4. Discussion**

327 In a controlled experimental setting, this study investigated whether differences in appetite, food reward
328 and eating behaviour traits, compared to non-SCI individuals, may contribute to the greater obesity
329 prevalence in those with SCI. We found that meal-related perceptions of appetite were no different
330 between groups but people with SCI exhibited stronger liking and motivation to consume sweet rather
331 than savoury foods. We also found that people with SCI exhibit higher levels of dietary cognitive
332 restraint compared with the non-SCI group. These findings suggest that SCI is associated with altered
333 hedonic factors impacting appetite and eating behaviour.

334 *4.1. Food reward*

335 We found that sweet appeal bias scores for 'relative preference', 'explicit wanting', and 'explicit liking'
336 were greater in persons with SCI compared to those without SCI, in both hungry and fed states. Lower
337 cravings for savoury foods in the group with SCI, as reported in the Control of Eating Questionnaire,
338 reinforced this finding. These findings indicate that people with SCI exhibit a greater overt preference

and desire to consume sweet rather than savoury foods. In the context of appetite, eating behaviour and energy balance, this finding is relevant as sweet foods are typically more energy dense, contain a high proportion of simple sugars, and have a weak effect on satiety (Hogenkamp, 2016). It is possible that this pleasure-related difference in appetite may contribute to a greater propensity for overconsumption, however, the cross-sectional nature of this study does not allow causal influence to be determined.

This finding is consistent with previous data which found that inactive men experienced a greater liking for sweet foods compared with active men (Horner et al., 2016). Notably, whilst data from our physical activity questionnaires indicated no clear difference in activity behaviours between study groups, it should be recognised that these questionnaires lack sensitivity, and that the group with SCI almost certainly expend less energy in daily activities each day. The relevance of physical inactivity is also supported by studies measuring food reward via fMRI. Herein, individuals displaying low levels of daily physical activity experienced greater activation of reward related brain regions in response to high-energy foods (Drummen et al., 2019; Killgore et al., 2013; Luo et al., 2018). Collectively, such differences in food hedonics may contribute to the established uncoupling between energy intake and energy expenditure in people who habitually demonstrate low levels of activity-related energy expenditure (Hopkins & Blundell, 2016).

We speculate that the higher levels of adiposity, found in persons with a SCI may have contributed to their greater preference and motivation for sweet foods (Dressler & Smith, 2013; Lampuré et al., 2016; Nakamura et al., 2001). As expected, although we matched groups for BMI, those with SCI were found to have 20% greater skinfolds and displayed significantly greater waist circumferences than the non-SCI group. These results are in-line with other literature in SCI (Spungen et al., 2003) and studies have shown obesity to be associated with impaired signalling systems, such as insulin and leptin resistance, and oxidative and endoplasmic reticulum stress (Berthoud et al., 2011). This creates a central toxic environment which leads to neural alterations in parts involved in reward processing, such as the corticolimbic system. These changes have been shown to accentuate the progression of obesity, insinuating that elevated adiposity increases food reward circuitry activity (Berthoud et al., 2011).

4.2. Cognitive restraint

A second notable finding was that cognitive restraint was higher in the group with SCI, indicating that a greater effort to limit day-to-day food intake is made in this group (Stunkard & Messick, 1985). Elevated levels of restraint may reflect the individuals' increased awareness of their lowered energy requirements and how, particularly in today's obesogenic environment, more psychological effort is required to prevent overconsumption and weight gain. Similarly, elevated body image concerns in persons with SCI, specifically around weight gain, may lead to changes in the quantity and type of foods the individual perceives acceptable to eat (Alysse Bailey et al., 2016).

It has been proposed that the elevated cognitive effort used to resist hedonic food cues for high-energy foods may result in increased wanting and craving (Adams et al., 2019; Veenstra & de Jong, 2010; Verzijl et al., 2018). This could infer that by exhibiting greater cognitive restraint against sweet foods, persons with SCI inadvertently develop an increase in food reward. However, the relationship between cognitive restraint, food reward, and energy intake, specifically of sweet or energy-dense foods, has not previously been explored in an SCI population. Further investigation into this relationship may provide more insight into how these factors influence weight gain and obesity in persons with SCI.

4.3. Satiety responsiveness and energy intake

Our research group have previously noted that postprandial satiety responses were greater in persons with SCI compared to a non-SCI group following an isoenergetic preload (Fenton et al., 2021). In our previous work we proposed that the preload represented a relatively larger meal for the group with SCI compared to the non-SCI group due to their lower energy requirements. This current study is the first to extend this hypothesis across a 4 h postprandial period following a breakfast meal with an energy content normalised to participants' RMR and found that appetite perceptions, including satiety, were not different in persons with SCI. Additionally, after the 4 h period, *ad libitum* energy intake, normalised to RMR, was similar in SCI and non-SCI groups. These data suggest that meal-related satiety perceptions are not 'dysregulated' as a result of SCI. Data from our hypothetical expected satiety questionnaire also support this idea, showing that persons with SCI do not perceive there to be any differences in the satiating abilities of a variety of foods compared to the non-SCI group.

A trend toward a lower absolute *ad libitum* energy intake was also seen in the group with SCI. In conjunction with the aforementioned findings, this could suggest that satiety perceptions in persons with SCI are upregulated to adjust for reduced energy demands. This notion is supported by the elevated levels of satiety responsiveness and cognitive restraint seen in the group with SCI, inferring that there could be both physiological and psychological factors influencing this adjustment. Whilst scores of momentary expected satiety and ideal portion size were not significantly different between groups, the non-SCI group recorded portion sizes that were 419 kJ and 558 kJ higher than the group with SCI, respectively, which further supports this concept. Our absolute energy intake data match this, suggesting that this study may have been underpowered to detect group differences. Altogether, alterations in meal-related and trait-based satiety profiles do not appear to underpin an enhanced obesity predisposition in people with SCI.

4.4. Strengths and limitations

The primary strength of this study was the recruitment of a hard-to-reach population that was matched to a control group for age, sex, and BMI. However, the heterogenous nature of the group with SCI with regards to injury level and motor function must be considered with regards to variability in study outcomes. In addition, given the exploratory nature of this study, multiple outcomes were examined

increasing the potential for Type I errors. Another potential limitation of this study was conducting an LFPQ after the *ad libitum* lunch meal, as the quantity of food was not standardised or normalised. Thus, the validity of this LFPQ may be questionable. Subsequent studies may benefit from conducting postprandial LFPQs following a meal normalised for energy requirements. Additionally, although skinfold thickness was (almost; $p = 0.059$) greater in the group with SCI, suggesting elevated levels of adiposity, no objective measures of body composition were conducted in the current study. The influence of accentuated adiposity as a rationale for group differences in food reward or eating behaviours should therefore be interpreted with caution. The use of questionnaires to assess habitual physical activity is another limitation of the current study, given the low reliability of self-reported physical activity status (Prince et al., 2008). Although, objective measures of physical activity status, such as wrist-worn accelerometers, have been validated in SCI populations against non-SCI controls (Murphy et al., 2019), these measures would not provide an accurate reflection of the interindividual differences in energy expenditure, which is an important consideration when assessing appetite- or energy intake-related measures.

4.5 Conclusions

In summary, food reward for sweet foods, as well as cognitive restraint, was greater in persons with SCI compared to the non-SCI group. In addition, postprandial appetite perceptions and subsequent *ad libitum* energy intake following a breakfast meal standardised for energy requirements, were not different between the SCI and non-SCI groups. Collectively, these findings highlight that altered satiety profiles do not appear to increase susceptibility to obesity in this population. Conversely, elevated food reward for sweet food in persons with SCI may lead to overconsumption.

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Author contributions

JMF, SPH, CJM, VLT and JAK conceived the study idea. JMF performed data collection, conducted the data analysis, and led the writing of the manuscript with the input of all authors. All authors reviewed and approved the final version of the manuscript.

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Ethical approval

All participants gave informed consent before taking part in this study. Ethical approval was given by Loughborough University Ethics Review (Human Participants) Sub-Committee (Study ID: 5574)

Declaration of competing interest

None.

Ethical statement

This research obtained ethical approval from Loughborough University's ethics review board before any study related procedures commenced (Study ID: 5574). All participants provided written informed consent to participate.

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