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Investigating the mediating role of physical activity within the association between food insecurity and BMI

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ABSTRACT

Food insecurity is linked with obesity and while the mechanisms behind this association are complex, lower levels of leisure-time physical activity in those with food insecurity may contribute to this. Individual-level factors (such as concerns of performing physical activity) may partly determine levels of physical activity within individuals with food insecurity, as such individuals may seek to minimise their levels of physical activity in order to preserve energy. Using the Food Insecurity Physical Activity Concerns Scale (FIPACS) (used to measure concerns of performing leisure-time physical activity, focusing on factors specific to food insecurity), the current study investigated whether the association between household food insecurity and body mass index (BMI) is explained by a mediation pathway of FIPACS scores and leisure-time physical activity. We also investigated whether the association between food insecurity and FIPACS scores is moderated by nutrition knowledge. Participants (N = 329, food insecure = 55) completed an online survey consisting of the FIPACS, the International Physical Activity Questionnaire long-form (IPAQ), the Diet, Disease, and Weight management sub-section of the General Nutrition Knowledge Questionnaire, a measure of diet quality, and self-reported BMI. Findings revealed that FIPACS scores and leisure-time physical activity did not mediate the association between food insecurity and BMI ($b < 0.01$, $SE = 0.01$). Additionally, nutrition knowledge did not moderate the association between food insecurity and FIPACS scores ($b = -0.09$, $SE = 0.08$). Findings suggest that concerns of performing physical activity in the context of food insecurity are unrelated to leisure-time physical activity, and that these two factors do not explain the association between food insecurity and BMI. Future research should investigate other factors in the link between food insecurity, physical activity, and BMI.

1. Introduction

Food insecurity, defined as limited and/or uncertain access to nutritionally adequate food is a widespread issue. Within the UK, a large proportion of individuals currently experience food insecurity, with the prevalence estimated to be around 14.8% (Food Foundation, 2024). Food insecurity is reliably associated with poorer diet quality (Hanson & Connor, 2014; Keenan et al., 2021) and greater obesity levels (Dhurandhar, 2016; Morales & Berkowitz, 2016).

Mechanisms underlying this association between food insecurity and obesity have been proposed through the resource scarcity hypothesis (Dhurandhar, 2016) and the insurance hypothesis (Nettle et al., 2017). The resource scarcity hypothesis argues that, when in an environment where high calorie foods are accessible, those of low social status demonstrate greater energy intake, a lower metabolic rate, and a lower level of energy expenditure, relative to individuals who have a high social status. A similar but distinct theory - the insurance hypothesis - argues that when experiencing food insecurity, evolutionary mechanisms which may help to combat the risk of starvation (i.e., consumption and efficient storage of energy) become active. Beyond these explanations, other factors relating to the food environment contribute to this association, such as the greater monetary cost of healthier diets (Johnstone et al., 2023) and use of food as a coping mechanism in response to distress associated with food insecurity (Keenan et al., 2021,

Abbreviations: FIPACS, Food Insecurity Physical Activity Concerns Scale; IPAQ, International Physical Activity Questionnaire; MET, metabolic equivalent of task; BMI, body mass index.

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2022; Spinosa et al., 2019).

The role of physical activity may also be an important contributor to the association between food insecurity and obesity. Previous research has demonstrated a negative association between food insecurity and physical activity (Bruening et al., 2018; Dhurandhar, 2016; Gulliford et al., 2006; Lee & Cardel, 2019; Martinez et al., 2019; To et al., 2014). Individual-level factors (i.e., psychosocial factors) have been implicated in the association between physical activity and socioeconomic status (SES) (Rawal et al., 2020), and are suggested to also affect physical activity levels in those with food insecurity. For example, Lee and Cardel (2019) proposed that, as an extension of the insurance hypothesis, individuals with food insecurity may minimise their levels of physical activity in order to preserve energy. To date, limited research has tested this suggestion – one randomised controlled trial conducted by Lee et al. (2022) found that in a sample of Hispanic adolescents who were randomised to experience high or low subjective social status, participants did not differ in the level of moderate-to-vigorous physical activity or sedentary behaviour. However, other evidence from qualitative research suggests that food insecure individuals may display patterns of energy preservation. Puddephatt et al. (2020) found that some users of food banks reported behaviours of energy preservation and of minimising physical activity as a strategy to cope with food insecurity. Currently, a gap in the literature remains as to whether food insecure individuals display a greater level of concern towards performing physical activity, and whether this in turn affects physical activity levels and adiposity.

Recently, Gough et al. (2024) created a measure to capture concerns of performing leisure-time physical activity within the context of food insecurity – the Food Insecurity Physical Activity Concerns Scale (FIPACS). An exploratory factor analysis of this scale suggested a four-factor solution. These were: 'Concerns relating to hunger', 'Concerns of replenishment and calories', 'Concerns of physiological effects of exercise' and 'Compensatory behaviours'. These factors appear to capture behaviours and concerns relating to energy preservation, and also the negative physiological effects of leisure-time physical activity, which may be exacerbated by poor diet quality due to food insecurity (Hanson & Connor, 2014). Gough et al. (2024) also demonstrated, through unplanned analyses, that scores on the FIPACS were positively associated with household food insecurity scores – those with a greater food insecurity score reported greater concerns of performing leisure-time physical activity. Unexpectedly, however, FIPACS scores were *positively* associated with self-report physical activity levels, measured using the International Physical Activity Questionnaire Short Form (IPAQ-SF), suggesting that FIPACS scores may not relate to a reduced level of physical activity *per se*. However, the IPAQ-SF does not differentiate between different domains of physical activity (e.g., household, transportation, occupational, and leisure-time physical activity). This is important because previous research investigating the link between socioeconomic status (a construct related to food insecurity) and physical activity has shown that only leisure-time physical activity is consistently positively associated with SES (Stalsberg & Pedersen, 2018). Furthermore, certain domains of physical activity may be outside of the control of individuals with food insecurity (e.g., occupational-based physical activity due to the nature of one's profession). Therefore, it may be possible that FIPACS scores are negatively related to leisure-time physical activity only, as an individual with food insecurity will likely have greater control over this form of physical activity. To address this question, the present study aimed to undercover the association between FIPACS scores and separate domains of physical activity (transportation, household, occupational, leisure-time) and also aimed to determine whether the association between food insecurity and BMI is mediated by higher FIPACS scores and lower levels leisure-time physical activity.

An additional aim of the study was to investigate whether the association between food insecurity and FIPACS scores is moderated by nutrition knowledge. Specifically, this association may depend on ones knowledge of nutrition, including an understanding of the effect that performing leisure-time physical activity may have on one's energy balance – a food insecure individual who lacks an understanding of this may score lower on the FIPACS compared with a food insecure individual who has a stronger understanding, because the understanding of what performing physical activity may mean for energy expenditure may determine the amount of concern an individual with food insecurity has in relation to performing physical activity.

Using an online survey, participants recorded self-report physical activity levels, household food insecurity scores, nutrition knowledge scores, FIPACS scores, BMI, and diet quality scores. We hypothesised the following.

Hypothesis 1. We predicted a serial mediation effect (see Fig. 1) - the association between household food insecurity and BMI would be mediated by scores on the FIPACS and levels leisure-time physical activity.

Hypothesis 2. Nutrition knowledge would moderate the association between household food insecurity scores and FIPACS scores.

2. Methods

2.1. Participants

The sample size was calculated using Kim's method (Kim, 2005). Based on 90% power at alpha = 0.05 (H0 Root Mean Square Error of Approximation (RMSEA) = 0; H1 RMSEA = 0.05), df = 118, it was calculated that 181 participants would be needed – this was our minimum target sample size. Four hundred and thirty respondents opened the survey (hosted on Qualtrics). After data cleaning, the final sample size consisted of 329 participants (see results section for details of reasons for respondents being excluded). Participants were recruited via two strategies. Firstly, participants were recruited via Prolific (an online participant recruitment platform) – stratification by sex was used for this recruitment strategy. Our second recruitment strategy was via social media (X, formerly known as Twitter) and word-of-mouth. Recruitment occurred between June and July 2023. The inclusion criteria were the following: live in the UK, be aged 18 or over, have no history of or current eating disorder(s), be fluent in English, be physically capable to complete physical activity (such as sport, exercise, walking for recreation). This last point of the criteria was included to ensure that participants do not produce low scores on the FIPACS or physical activity scales simply because they are unable to perform physical activity. Participants who completed the survey through Prolific were reimbursed for their time. The study received ethical approval from the University of Liverpool Institute of Population Health Research Ethics Committee (reference: 12415). The study protocol and analysis plan were pre-registered: https://osf.io/pd6ey/

2.2. Measures

Food Insecurity Physical Activity Concerns Scale (Gough et al. (2024); FIPACS). The FIPACS is a validated questionnaire which measures concerns relating to performing physical activity within the context of food insecurity. Responses were scored on a 5-point Likert scale, ranging from 'Strongly disagree' to 'Strongly agree'. The FIPACS consists of four factors (these are listed with internal reliability scores for the current sample): 'Concerns of replenishment of calories' ($\omega_t = 0.89$), 'Physiological effects of physical activity' ($\omega_t = 0.68$), 'Concerns relating to hunger' ($\omega_t = 0.90$), 'Compensatory Behaviours' ($\omega_t = 0.81$). The total score of the FIPACS was used. Higher scores are indicative of greater concerns of performing physical activity. Internal reliability for all items for the current sample was $\omega_h = 0.74$.

Household Food Insecurity. The 10-item United States Department of Agriculture (USDA) Household Food Security Survey Module was used to measure food insecurity levels (United States Department of Agriculture, 2012). These items measure the frequency with which

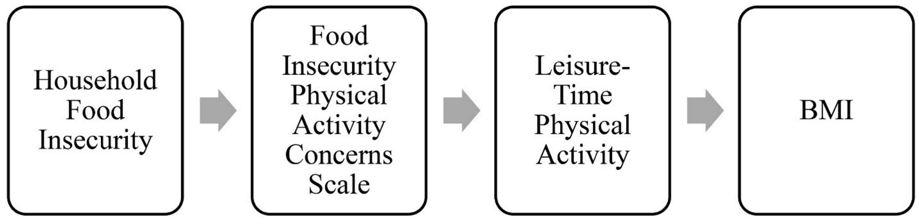

Fig. 1. Hypothesised pathway of indirect effect.

participants had difficulties in acquiring food due to a lack of money within the last 12 months. Responses of "Often true", "Sometimes true", "Almost every month", "Some months but not every month", and "Yes" were scored as 1, all other responses were scored as 0. Scores range from 0 (low food insecurity) to 10 (high food insecurity). The USDA also provides guidance for categorising scores as food insecure and food secure: scores 0–2 can be described as 'food secure' whereas scores 3–10 can be described as 'food insecure'. Internal reliability of this measure for the total current sample was $\omega_t = 0.93$.

General Nutrition Knowledge Questionnaire (Kliemann et al., 2016). Section 4 of the General Nutrition Knowledge Questionnaire was included (Diet, disease and weight management). This section asks questions about which diseases are related to different foods and also on questions relating to weight management. We chose this section because of its focus on weight management, which may plausibly be related to one's ability to understand the role of physical activity in energy expenditure. This scale consists of 16 items and is scored out of 21, with higher scores indicative of greater nutrition knowledge. One question has a maximum score of six, making the maximum possible score greater than the number of questions. Internal reliability of this measure for the total current sample was $\omega_t = 0.73$.

International Physical Activity Questionnaire long-form (Craig et al. (2003); IPAQ). Participants reported physical activity levels over the last seven days. Participants were asked on how many of the seven days and how long on one of those days did they spend doing vigorous physical activity, moderate physical activity, and walking in relation to different types of activities: occupational, transportation, household, and leisure-time. Participants were also asked how much time they spent sitting (data not included in the analysis model). The metabolic equivalent of task (MET) for each domain of physical activity was calculated and multiplied by the duration and frequency of the physical activity – expressed as MET-minutes per week (MET-min/wk). To calculate total physical activity, MET-min/wk scores across all domains were summed together. In line with guidelines (IPAQ, 2005), scores were excluded where the combined amount of time for all exercise across all domains per day exceeded 960 min. Additionally, responses of less than 10 min of each activity were re-coded as zero minutes.

Diet Quality. Participants were also asked to report details of their diet using a validated measure (Robinson et al., 2017). This consisted of 20 items assessing food frequency. Responses were scored on a 10-point scale (1 = Never, 10 = 6+ per day). A diet quality score was obtained by recording frequencies as number of times per week, standardising participant scores by subtracting the means and dividing by the standard deviations for each food, multiplying each food by a pre-specified coefficient (as stated in Robinson et al. (2017)), and then summing all of these scores for each participant. Greater scores on this scale are indicative of a diet conforming to healthy eating recommendations.

BMI. Participants were asked to provide self-report height and weight measures. In order to ensure that self-reported height and weight are of a good standard, responses outside of a biological plausible range (1.22–2.13 m for height and 34–227 kg for weight) were used as cut-offs, as has been done in previous research (Kersbergen & Robinson, 2019; Noël et al., 2010) – participants who provided scores outside of this range were excluded from all analyses. Although self-reported height and weight offers practical advantages over in-person measurements, this form of measurement is susceptible to social desirability bias and recall error (Hattori & Sturm, 2013) with underestimating of weight more common among those with a higher BMI (Stommel & Schoenborn, 2009). However, despite these biases, self-reported and measured height and weight are strongly correlated (Pursey et al., 2014).

Demographic questions. Participants reported their gender, age, household income, ethnicity and highest education qualification.

Attention and quality checks. Within the measures included in the study, two attention checks were embedded – one in the diet quality questionnaire ('Please select Never') and the other in the FIPACS ('Please select Strongly Agree'). Participants who failed both of these attention checks were excluded from all analyses. For participants recruited outside of Prolific, the beginning of the survey included a reCAPTCHA to protect against the generation of invalid data via bots or malicious programs.

2.3. Procedure

Participants began by providing informed consent. They then completed the IPAQ, USDA Household Food insecurity 10-item module, FIPACS, diet quality measure, general nutrition knowledge questionnaire, ethnicity, education level, household income, age, gender, weight and height, and were debriefed.

2.4. Analysis plan

A structural equation model was used to investigate whether household food insecurity scores were indirectly associated with BMI via FIPACS scores and leisure-time physical activity levels. Modelling was conducted in R using the 'Lavaan' package. Model fit was assessed by calculating the Tucker Lewis index (TLI) and Comparative Fit Index (CFI), examining the Root Mean Square Error of Approximation (RMSEA), and Standardised Root Mean Square Residual (SRMR). Interpretations of those statistics are the following: TLI and CFI values above 0.90 are deemed acceptable. RMSEA value indications are <0.06 for good fit, between >0.06 and <0.08 for an acceptable fit (Hu & Bentler, 1999; MacCallum et al., 1996). Lastly, for SRMR, values < 0.08 are considered a good fit (Hu & Bentler, 1999). Participants who had any missing data for any variables included in the structural equation model were removed from analyses. We also inspected modification indices and, if equal to or greater than ten, covariance pathways were added. See Fig. 2 for proposed model.

For the direct and indirect effects, unstandardized coefficients (along with their standard error) are reported with 95% confidence intervals and p-value. The nutrition knowledge, food insecurity, and the food insecurity x nutrition knowledge variables were mean centred. To test hypothesis 2, if the association between the food insecurity x nutrition knowledge variable and FIPACS scores was significant, we planned to further break this down – testing the association of food insecurity on FIPACS scores at the following levels of nutrition knowledge: 1 SD of the sample mean, sample mean, and +1 SD of the sample mean.

Due to there being considerably more variance in MET scores within each of the physical activity domains compared to the other variables in the model, there were convergence issues. To deal with this issue, MET scores were divided by 60 for the analysis, however original MET scores

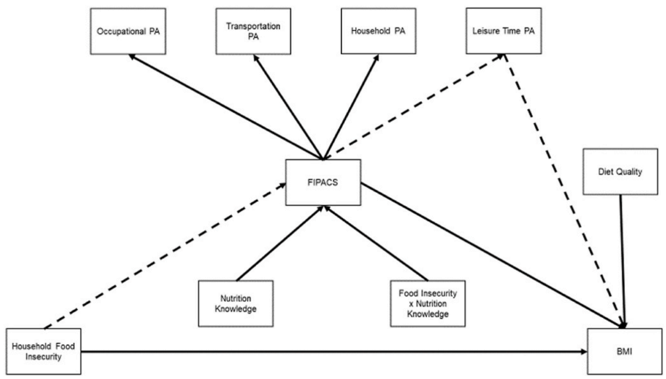

Fig. 2. Full proposed model. Dashed lines represent the hypothesised indirect effect pathway. Please note. The model in our pre-registered protocol included endogenous variables relating to the separate components of each physical activity domain with pathways coming from each domain. However, inclusion of these pathways produced a poor model fit, and were therefore removed.

are reported as descriptive statistics (Fig. 2).

3. Results

After excluding cases based on providing incomplete responses (N = 74), implausible self-reported height or weight (N = 4), exceeding the IPAQ guideline cut-off of performing physical activity greater than 960 min a day (N = 16), failing both attention checks (N = 4), exceeding the IPAQ guideline cut-off and failing both attention checks (N = 1), providing an incomplete response, exceeding the IPAQ guideline cut-off, and failing both attention checks (N = 2), a final sample size of 329 participants were included for all analyses. See descriptive statistics of participants in Table 1.

3.1. Planned analyses

A structural equation model was produced in order to test the hypothesised indirect effect that household food insecurity would be indirectly associated with BMI via FIPACS scores and leisure-time physical activity.

Due to some of the variables in the model having a non-normal distribution, a maximum likelihood estimator with a Satorra-Bentler correction was used when fitting the model. The overall fit of the model was mixed: CFI and TLI scores were both below an acceptable level (CFI = 0.797, TLI = 0.640), however RMSEA indicated good fit (RMSEA = 0.052) as did SRMR (SRMR = 0.055), AIC = 17735.033. Inspection of modification indices revealed that a covariance pathway between leisure-time and transportation physical activity should be created (modification index = 13.695). After adding this pathway, model fit indicators were the following: $\chi^2 = 121.75$, df = 39, CFI = 0.925; TFI = 0.860; RMSEA = 0.032; SRMR = 0.045, AIC = 17722.693.

Household food insecurity was positively associated with FIPACS scores. Nutrition knowledge scores were negatively associated with FIPACS scores. However, the food insecurity x nutrition knowledge interaction term was not significantly associated with FIPACS scores, therefore follow-up analyses (as described in the data analysis section) were not performed on the association between the interaction term and FIPACS scores (see Table 2).

The hypothesised indirect effect (as shown in Table 3) was not significant. As can be seen in Figure 3, the path between FIPACS and leisure-time physical activity was nonsignificant. See Table 2 for a list of direction associations between variables within the model. Of note, FIPACS scores were positively associated with occupational physical activity. When asked if participants ‘currently have a job or do any unpaid work outside your home’, 75 answered ‘No’. Removing these participants from the analysis increased the effect size of the association between FIPACS and occupational physical activity (b = 1.35, [95% CI = 0.46, 2.25], SE = 0.46, p = .003).

Table 1
Descriptive statistics of participant characteristics and questionnaire scores.

Measure	Mean ± SD or frequency counts
BMI (kg/m^2)	27.68 ± 7.98
Age (years)	41.74 ± 13.60
FIPACS (out of 80)[a]	31.56 ± 11.31
Household Food Insecurity Score (out of 10)[a]	1.16 ± 2.19
Food Insecurity Status (Insecure:Secure)	55:274
Total Occupational MET-min/wk[a]	1972.12 ± 3881.32
Total Transportation MET-min/wk[a]	1065.96 ± 1355.48
Total Household MET-min/wk[a]	1689.53 ± 1919.50
Total Leisure-Time MET-min/wk[a]	1278.96 ± 1550.42
Total Physical Activity MET-min/wk[a]	6006.58 ± 5173.18
Nutrition knowledge (out of 21)[a]	14.32 ± 3.15
Diet Quality Score[a]	−0.01 ± 0.97
Gender (Female:Male:Non-binary)	165:163:1
Household income[b]	£47,987.18 ± 39,356.81
Household income (<£5200)	15
Household income (£5200 to £10,399)	6
Household income (£10,400 - £15,599)	13
Household income (£15,600 - £20,799)	17
Household income (£20,800 - £25,999)	25
Household income (£26,000 - £36,399)	61
Household income (£36,400 - £51,999)	85
Household income (£52,000 - £77,999)	64
Household income (≥£78,000)	41

[a] Higher scores indicative of greater concerns of performing physical activity (FIPACS), greater food insecurity, greater levels of physical activity, greater nutrition knowledge, healthier diet quality.
[b] Data missing from two participants.

3.2. Sensitivity analysis

After removing participants whose height and weight fell outside of the biologically plausible range, the sample still consisted of a number of participants whose self-reported BMI was greater than 50, scoring as highly as 94.67. As some of these scores are likely to be erroneous, we conducted a sensitivity analysis whereby participants whose BMI was 50 or greater – a recommended cut-off used in previous research (Armour et al., 2016) - were excluded from the main analysis, resulting in the removal of seven participants. When running the primary analysis again

Table 2
Direct associations between variables (unstandardized regression coefficients).

Association	b(SE)	p-value	95% CI
Household Food Insecurity - > FIPACS	1.51 (0.30)	<0.001	0.92, 2.10
Household Food Insecurity - > BMI	0.24 (0.16)	0.140	−0.08, 0.56
Household Food Insecurity x Nutrition Knowledge - > FIPACS	−0.09 (0.08)	0.278	−0.25, 0.07
FIPACS - > Total Occupational MET	0.84 (0.34)	0.014	0.17, 1.50
FIPACS - > Total Transportation MET	0.08 (0.13)	0.520	−0.17, 0.34
FIPACS - > Total Household MET	−0.22 (0.15)	0.125	−0.51, 0.06
FIPACS - > Total Leisure-Time MET	−0.08 (0.13)	0.528	−0.33, 0.17
FIPACS - > BMI	0.02 (0.04)	0.667	−0.06, 0.10
Nutrition Knowledge - > FIPACS	−0.60 (0.18)	0.001	−0.95, −0.25
Diet Quality - > BMI	−0.61 (0.45)	0.175	−1.48, 0.27
Total Leisure-Time MET - > BMI	−0.03 (0.01)	0.029	−0.06, −0.00

Table 3
Hypothesised indirect effect.

Hypothesised indirect effect	b(SE)	p-value	95% CI
Food insecurity - > FIPACS - > Leisure-time PA - > BMI	0.00 (0.01)	0.537	−0.01, 0.02

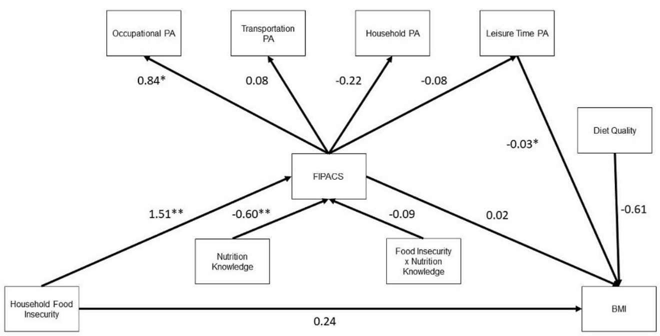

Fig. 3. Associations between the variables of the model. Values are unstandardized regression coefficients. *p < .05, **p < .01.

with these participants removed, the association between BMI and diet quality became significant (b = −0.63, [95% CI = −1.22, −0.04], SE = 0.30, p = .037). The statistical significance of all other associations remained unchanged.

As socioeconomic status is associated with both food insecurity and physical activity, we performed the analysis again with the inclusion of paths between household income and each of the physical activity domains and between household income and FIPACS scores. Findings revealed that the statistical significance of all paths remained unchanged (see supplementary materials for table of direct associations).

3.3. Exploratory analyses

The present study did not formally set out to investigate the associations between food insecurity and physical activity, however performing this analysis would aid interpretation of the current study findings. We performed the analysis twice – first as unadjusted associations between food insecurity and each domain of physical activity (total physical activity is also reported for completeness) (presented in Table 4), and again adjusted, by using the original structural equation model and adding paths between food insecurity, and each physical activity domain (presented in Table 5). Findings revealed that the only significant association was the unadjusted association between household food insecurity and occupational physical activity, however this was nonsignificant when measured as an adjusted association.

Table 4
Unadjusted associations between physical activity domains (and total physical activity) and food insecurity score.

Association	b(SE)	p-value	95% CI
Household Food Insecurity - > Total Occupational MET	3.38 (1.64)	0.040	0.16, 6.60
Household Food Insecurity - > Total Transportation MET	−0.12 (0.61)	0.850	−1.31, 1.08
Household Food Insecurity - > Total Household MET	0.23 (1.00)	0.821	−1.73, 2.18
Household Food Insecurity - > Total Leisure-Time MET	−0.72 (0.59)	0.227	−1.88, 0.45
Household Food Insecurity - > Total Physical Activity MET	2.77 (2.17)	0.202	−1.49, 7.03

Table 5
Adjusted associations between physical activity domains and food insecurity score. Associations were adjusted by using the original structural equation model used in the primary analysis and adding paths between household food insecurity and each physical activity domain.

Association	b(SE)	p-value	95% CI
Household Food Insecurity - > Total Occupational MET	2.23 (1.77)	0.208	−1.24, 5.70
Household Food Insecurity - > Total Transportation MET	−0.18 (0.65)	0.783	−1.46, 1.10
Household Food Insecurity - > Total Household MET	0.66 (1.06)	0.535	−1.42, 2.73
Household Food Insecurity - > Total Leisure-Time MET	−0.09 (0.12)	0.445	−0.33, 0.14

4. Discussion

The present study aimed to investigate whether the association between food insecurity and BMI is mediated by concerns of performing physical activity (as measured using the FIPACS), and leisure-time physical activity. We predicted a significant indirect effect between food insecurity, FIPACS scores, leisure-time physical activity, and BMI. Findings revealed that this indirect effect was nonsignificant, suggesting that the association between food insecurity and BMI is not explained by concerns of performing leisure-time physical activity and actual levels of leisure-time physical activity. Furthermore, the present findings revealed a nonsignificant association between the nutrition knowledge by food insecurity interaction term and FIPACS scores, going against our prediction that nutrition knowledge would moderate the association between food insecurity and FIPACS scores.

Previous studies have found that food insecurity is negatively associated with physical activity (Bruening et al., 2018; Dhurandhar, 2016; Gulliford et al., 2006; Lee & Cardel, 2019; Martinez et al., 2019; To et al., 2014). We proposed that this negative association could, in part, be due to the individual-level factor of concerns relating to performing physical activity – namely scores on the FIPACS. Previously, FIPACS scores have been shown to be weakly *positively* associated with physical activity as measured using the short-form version of the International Physical Activity Questionnaire (Gough et al., 2024). However, this measure of physical activity does not differentiate between domains of PA. The present study measured PA using the long form version of the IPAQ – a measure of physical activity which does differentiate between different domains of PA. Findings showed that, unexpectedly, FIPACS scores were not associated with leisure-time physical activity, despite the FIPACS being designed to focus specifically on concerns relating to this domain of PA. One explanation for this nonsignificant association could be due to other competing factors which may also determine physical activity levels. Engagement in physical activity is thought to be determined by a range of factors which include individual-level factors but also extend beyond these, including microsystem level (e.g., friends and family), mesosystem level (e.g., the interaction between individual and group factors), exosystem level (i.e., surrounding environment), and macrosystem level factors (i.e. government, regulatory bodies) (Rawal et al., 2020). One explanation of this nonsignificant association then, is that although concerns of performing physical activity are related to food insecurity (as shown by the positive association between food insecurity and FIPACS scores), other factors (e.g., social support, urban planning, work-life integration, financial constraints) may ultimately exert a greater influence in determining the level of physical activity performed, therefore meaning that concerns of physical activity ultimately do not determine the level of leisure-time physical activity performed.

Although no significant association between FIPACS scores and leisure-time physical activity was found, results did reveal a significant association between FIPACS and occupational PA (albeit a relatively small one). One explanation of this finding could be due to the fact that food insecurity was found to be associated with both FIPACS scores and occupational PA, therefore the association between FIPACS and occupational PA could be partially driven by food insecurity being linked with occupational PA, this is in line with previous research which has shown that occupational physical activity is negatively associated with socioeconomic status (Beenackers et al., 2012; Stalsberg & Pedersen, 2018). An alternative explanation for this association between FIPACS scores and occupational PA could be that for those who do perform physically active jobs and are food insecure, greater concerns of performing leisure-time physical activity (indicative of greater FIPACS scores) are displayed because these individuals have a physically demanding job, that is to say that having a physically demanding job leads to a greater reluctance to perform any additional physical activity beyond what is required for one's job.

For our second hypothesis, we predicted that nutrition knowledge scores would moderate the association between food insecurity and FIPACS scores. However, the nutrition knowledge by food insecurity interaction term was not significantly associated with FIPACS scores, suggesting that nutrition knowledge scores do not moderate the association between food insecurity and FIPACS scores. One explanation for this null finding could be that a high level of nutrition knowledge is not needed to understand the contributing factor of leisure-time physical activity on energy expenditure and how this may relate to energy balance and preservation – that is, performing leisure-time physical activity is widely understood to result in energy expenditure. Unexpectedly as well, nutrition knowledge was negatively associated with FIPACS scores. Although we did not hypothesise an association between these two variables, greater nutrition knowledge may have been expected to be positively associated with FIPACS scores. This is because a greater understanding of aspects relating to nutrition and weight management may lead to a greater awareness of energy preservation, intake, and expenditure (i.e., an accurate understanding that physical activity is a source of energy expenditure), ultimately producing an increase in concerns of performing physical activity.

Of note, the present findings failed to show a significant direct association between food insecurity and BMI. Previous findings, although mixed, are generally indicative of a positive association between food insecurity and BMI (Dhurandhar, 2016; Morales & Berkowitz, 2016). One reason for why a nonsignificant association was observed in the present study could be because this effect has, in some studies, previously been found in women, but not men (Gooding et al., 2012; Morales-Ruán et al., 2014; Pan et al., 2012). It is therefore possible that, because the sample was mixed-gendered, a significant effect was not detected. Relatedly, it is unclear why the associations between food insecurity and separate domains of physical activity (as well as total physical activity) were largely nonsignificant. One possibility could be that, due to the limited number of individuals with food insecurity in the sample, the associations were harder to detect.

The present study has a number of strengths and limitations. A strength of the research is that the sample achieved a nearly even split of females and males (165 and 163 respectively) and used validated questionnaires to assess key constructs within this study. In terms of weaknesses, participants were exclusively based in the UK, and the vast majority of participants were of white ethnicity (90.9%), meaning that generalisability to other countries and ethnicities may not be possible, however this split of ethnicities is somewhat comparable to the percentage of people who are of white ethnicities in parts of the UK (e.g., the percentage is 82% in England and Wales (UK Government, 2021)). Similarly, the study had an uneven number of people who were and were not experiencing food insecurity (16.7% were classed as having a food insecure status), meaning that food insecurity scores were positively skewed. Again, however, this percentage is representative of the level of food insecurity in the UK (14.8%; Food Foundation (2024)). An additional limitation was that self-report measures of physical activity were used. Findings may have had greater accuracy if objective measures of physical activity were incorporated (e.g., use of accelerometers). A final limitation of the study is that this data is cross-sectional, therefore inferences relating to causality must be made with caution.

In conclusion, the present study found that the association between food insecurity and BMI does not appear to be mediated by FIPACS scores and leisure-time PA. Future research may wish to further elucidate the role that physical activity plays in relation to the association between food insecurity and BMI. Additionally, the factors contributing to food insecurity and physical activity should be further explored. Collectively, the present study (along with previous research (Gough et al., 2024) has not found evidence to show that concerns of performing physical activity are significantly associated with physical activity levels (with the exception of occupational PA). Therefore, other factors warrant investigation in the future.

Ethical approval and consent to participate

This study was approved by the University of Liverpool research ethics committee.

CRediT authorship contribution statement

Thomas Gough: Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Conceptualization. **Olivia Brown:** Writing – original draft, Formal analysis, Conceptualization. **Paul Christiansen:** Writing – review & editing, Formal analysis. **Charlotte A. Hardman:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Gregory S. Keenan:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization.

Availability of data and materials

The study dataset, pre-registered protocol, and R analysis code is available on the Open Science Framework repository at https://osf.io/pd6ey/

Competing interests

CAH and PC receive research funding from the American Beverage Association for work outside of the submitted manuscript. CAH has also received speaker fees from International Sweeteners Association and the International Food Information Council.

Consent for publication:

N/A.

Ethics approval and consent to participate

All participants provided written informed consent to participate. Ethical approval was gained by the University of Liverpool Institute of Psychology, Health and Society Research Ethics Committee.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2024.107724.

Data availability

I have shared the link to the data within the manuscript.

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