QUANTITATIVE RESEARCH

Using GPS and activity tracking to reveal the influence of adolescents' food environment exposure on junk food purchasing

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ABSTRACT

OBJECTIVES: This study examines the influence of adolescents' exposure to unhealthy food outlets on junk food purchasing during trips between home and school, with particular attention to how exposure and purchasing differ according to child's biological sex, mode of transportation, and direction to or from school.

METHODS: Between 2010 and 2013, students ($n = 654$) aged 9–13 years from 25 schools in London and Middlesex County, ON, completed a socio-demographic survey and an activity diary (to identify food purchases), and were observed via a global positioning system for 2 weeks (to track routes for trips to/from school). Spatial data on routes and purchase data were integrated with a validated food outlet database in a geographic information system, and exposure was measured as the minutes a child spent within 50 m of an unhealthy food outlet (i.e., fast food restaurants, variety stores). For trips involving junk food exposure ($n = 4588$), multilevel logistic regression was used to assess the relationship between exposure and purchasing.

RESULTS: Multilevel analyses indicated that adolescents' duration of exposure to unhealthy food outlets between home and school had a significant effect on the likelihood of junk food purchasing. This relationship remained significant when the data were stratified by sex (female/male), trip direction (to/from school) and travel mode (active/car), with the exception of adolescents who travelled by bus.

CONCLUSION: Policies and programs that mitigate the concentration of unhealthy food outlets close to schools are critical for encouraging healthy eating behaviours among children and reducing diet-related health issues such as obesity.

KEY WORDS: Built environment; food environment; GPS; food purchase; diet; child; adolescent

La traduction du résumé se trouve à la fin de l'article.

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Some of the most critical public health issues facing Canadians (e.g., obesity, heart disease, stroke, hypertension and type 2 diabetes) are linked to poor nutrition.[1] Among other variables, poor dietary habits have contributed to adverse health outcomes among Canadian adolescents: nearly one third are overweight or obese.[2] Obesity and other diet-related health issues arise not only from individual-level factors (e.g., genetics, lifestyle) but also from the characteristics of our local environments that discourage healthy diets, such as the presence of unhealthy food outlets.[3–6] Neighbourhood food environments can have a particularly strong influence on children, including adolescents, who tend to be more restricted geographically than adults and who are therefore more captive to their local built environments, including food outlets, recreational spaces and transportation infrastructure.[7,8] Understanding the local food environment is therefore important to encouraging healthy lifestyles among adolescents.[9]

Despite increasing acknowledgements of the importance of the built environment for health, it remains poorly conceptualized in much public health work. Researchers at the forefront of the field have advocated the combination of GPS(global positioning system)-derived activity spaces with activity/food diaries to better link junk food exposure and purchasing behaviours.[10–12] In this paper, we evaluate the relationship between junk food exposure and purchasing behaviour among adolescents during the school day, while controlling for sex, mode of transportation, and direction of the trip between home and school.

Addressing bias in geospatial proxies

Sadler and Gilliland[10] showed how geospatial proxies rather than direct measurements continue to be used to evaluate exposure to junk food. Most proxies have included calculating the density of junk food outlets in a child's home or school neighbourhood, or

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both.[3–5,13,14] Such density estimates are typically calculated within a buffered walkable zone (typically between 400 and 1600 m and measured along the street network or "as the crow flies") around home and/or school, or within the boundaries of a more arbitrary administrative unit, such as the census tract or census dissemination area where the home or school is located. Each method is susceptible to the modifiable areal unit problem, because any observed association may change depending on which scale of areal unit is employed.[15] Williams et al.[16] have cautioned against the use of such metrics because "predominant exposure measures may not account for what individual children actually experience" (p. 359).

Because of the lack of certainty in measurement, the population-level modelling approach common to most studies has been critiqued for creating biases in classification. For instance, user-defined activity spaces have been characterized as subjective constructions of travel surveys and food store listings.[17] While the use of activity spaces overcomes the limitations of grounding exposure to one location, researchers have advocated for more detailed individual-level neighbourhood assessments.[10,14–16]

Objectively measured aspects of the built environment, such as GPS tracking of activity spaces, offers an advance in the level of certainty in approximating a child's food environment. GPS tracking is more accurate for quantifying activity spaces than estimations by parents or participant self-report.[18] In one case, Harrison et al.[19] showed that GPS trips accounted for 50% more food outlets on children's trips home from school when compared with assumed trips.

New work emphasizes the need to focus "on combining GIS [geographic information systems]-based objective measurement of the community food environment with self-report measures" (p. 13).[20] Others refer to this as a need for "ego-centred definitions of areas that approximate individuals' local activity spaces" (p. 227).[21] A recent observational study using self-report measures found that children who ride home from school in private automobiles eat more snacks and candy than those who walk.[22] As that study did not use GPS tracking to delineate and characterize the food environment through which children travelled, important questions remain about the role of exposure.

The objective of this study is to explore the nature of the relationship between junk food purchasing (JFP) and the level of exposure to junk food outlets (JFOs). We achieved this objective by assessing the magnitude of this relationship and considered three trip-level control variables: 1) mode of transportation (active, bus and car); 2) trip direction (to school and from school); and 3) child's biological sex (females and males).

METHODS

Data collection

Data were collected as part of the Spatial Temporal Environment and Activity Monitoring (STEAM) Project (steamproject.ca). The STEAM Project compiled demographic, behavioural and GPS tracking data on 932 adolescents aged 9–13 years from communities in southwestern Ontario. The central aim of STEAM is to explore and assess how the physical (built and natural) environment influences adolescents' activity patterns and food consumption habits. This study was conducted with approval from the University of Western Ontario's Non-Medical Research Ethics Board (REB#: 17918S).

Data were collected over four years (2010–2013), each child being observed for one week in the spring and one week in the fall. The current study uses data from 511 adolescents from 25 elementary schools in Middlesex County and the City of London (Middlesex-London), which are characterized by a broad range of built forms and social environments. Adolescents completed socio-demographic questionnaires and daily activity diaries each week, answering questions about physical activity, eating habits and social/familial engagements. Adolescents indicated for each day whether they had purchased something on their way to or from school and the location of that purchase.

GPS tracks for every child were collected every second between the child leaving for school and the child returning home. Data derived from these GPS tracks included the mode of transportation (e.g., walk, bike, bus, car), time of day, and a key field to link with child-specific individual-level characteristics.

Every JFO in the region was extracted from the Middlesex-London public health inspector's food outlet database and geocoded (using principles of accuracy as discussed in Healy and Gilliland[23]) in a GIS (ArcGIS 10.1, Environmental Systems Research Institute, Redlands, CA). Given average road widths and typical viewsheds within our community, 50 m buffers were calculated around every unhealthy food source to help measure exposure.[10,19] These buffers were combined in GIS with GPS data on trips to give a measure of the number of minutes each adolescent was exposed to junk food sites on each trip to and from school.

The final data used in this study combined the individual GPS trips and modelled exposure values for each trip with data from the activity diaries, which indicated any JFP along the trip to and/or from school. These combined data provide the ability to analyze the relationship between exposure and JFP on a trip-by-trip basis. The study uses the trips to and from school because adolescents indicate that they have the most autonomy during these times.[24] This final set of trips for adolescents exposed to junk food were used for the final analysis, as a trip without exposure provided no opportunity to purchase junk food.

Analysis methods

The dependent variable, JFP, is a binary variable indicating whether junk food was purchased or not on the trip. It is calculated for each trip to and from school for each adolescent on the basis of the activity diary entries. Junk food was considered unhealthy food items purchased from fast food or variety stores, pizza places and ice cream shops.

The key independent variable, exposure to JFOs, was defined as the number of minutes during which a child was exposed (i.e., within 50 m) to fast food, variety stores, pizza places or ice cream shops (ranges from 0 sec to 350 min). This variable was truncated at 17 min (1020 sec) to account for significant outliers of exposure.

Three control variables were hypothesized to influence the relationship between exposure and food purchasing: biological sex, mode of transportation, and direction of the trip. Sex was defined as male and female. Mode of transportation was defined for each trip, including active modes (bike, walk, scooter or skateboard), car, and bus (school bus or city transit). The direction of the trip was either to or from school.

This study uses multilevel logistic regression, a commonly used technique with a binary outcome variable that takes into account clustering within the data. Individual trips are not independent but nested within adolescents; data on individual trips from a given adolescent are expected to be more alike than data collected from another adolescent. The study first assessed the overall effect of JFO exposure on JFP. The strength of this relationship was then examined separately for each category of one of the three control variables. Since this was an exploratory analysis, no multivariate models or models with interaction effects were tested. Both the linear and the quadratic effects were evaluated; none of the quadratic terms, however, were significant at the $p = 0.05$ level. To ease interpretability of the effects, the predicted probabilities of JFP were computed from across a range of exposure values (from "up to 1 min" to "up to 17 min") and plotted separately for each category of the three control variables. Predicted probabilities were computed from multilevel logistic regression models using both the intercepts and corresponding regression coefficients.

Child-level variances in JFP were also estimated by specifying the intercepts in all multilevel regression models as random. The amount of variation in JFP across adolescents was assessed by the intra-class correlation coefficient (ICC) and median odds ratio (MOR). The ICC was calculated by dividing the cluster-level variance by the total variance, representing the proportion of variance attributed to differences among adolescents. To calculate the ICC for the binary variable, the trip-level (level one) variance was fixed to the variance of the standard logistic distribution.[25] The MOR converts the cluster-level variance to an odds ratio scale and, as a consequence, it can be compared directly with odds ratios for fixed effects.[25] A large MOR implies large variation across adolescents, whereas a value of 1 suggests no such variation. The multilevel models are computed using Mplus.[26]

RESULTS

Descriptive statistics

In total, we observed 7,499 individual trips from 654 adolescents in Middlesex-London with both GPS and food purchasing data from recall diaries; 4,588 of these trips, from 511 children, involved exposure to junk food and were therefore retained for analysis. Of these 4,588 trips, 224 (4.9%) involved JFP. The average number of observed trips per child was 9, ranging from 1 to 20, and the prevalence of JFP among adolescents ranged from 0.0% to 100.0%. Additional characteristics included: more females (58.7%) than males (41.3%); more valid trips from (51.6%) than to (48.4%) school; and a modal split of 39.0% by bus, 30.8% by active modes and 30.2% by car.

Factors associated with junk food purchasing

Overall Effect

The results from the multilevel logistic regression analysis reported in Table 1 indicate that as exposure (measured in minutes) increased, the odds that junk food was purchased on that trip increased significantly. The OR for JFP associated with a 1-min increase in exposure to JFOs was 1.174 (95% CI [confidence interval] 1.14–1.21). The trip-level results from a multilevel model should be interpreted as ORs for within-cluster comparisons; they compare two trips observed in the same child. Figure 1a indicates that the probability of JFP increased from approximately 1.7% for trips with exposure of less than 1 min to 15.8% for trips with exposure of between 16 and 17 min. Finally, JFP across adolescents varied significantly, corresponding to an ICC of 0.499 and an MOR of 5.613. Thus, about 50% of the variance in the likelihood of JFP was due to differences between adolescents, and the MOR of 5.613 suggests a substantial difference between two trips with the same level of exposure but made by different, randomly chosen adolescents.

Mode of Transportation

Stratification of the focal relationship by the mode of transportation indicated that the relationship between exposure to JFOs and JFP was statistically significant and positive for data involving trips made by active modes of transportation and for trips made by car, but not significant for trips made by bus. The ORs for JFP associated with a 1-min increase in exposure for active and car travel were 1.13 (95% CI 1.06–1.20) and 1.22 (95% CI 1.16–1.28) respectively. Figure 1b indicates that the rate of increase in the predicted probabilities of JFP was much steeper for trips made by car than for trips made by active modes of transportation, increasing from 2.7 times more likely at 5 min to 4.4 times more likely at 15 min. Finally, the variation in JFP across adolescents was lowest for trips made by car (ICC = 0.459; MOR = 4.914) and the highest for active trips (ICC = 0.610; MOR = 8.705), the trips made by bus falling in the middle (ICC = 0.541; MOR = 6.546).

Trip Type

Stratification by route to or from school indicated that the relationship between JFO exposure and JFP was statistically significant and positive for data involving trips made to and from school. These effects translate into ORs of 1.22 (95% CI 1.12–1.33) and 1.12 (95% CI 1.08–1.16) respectively. Figure 1c shows that, although the effect of exposure was slightly more pronounced for trips to school, trips from school were much more likely to be associated with JFP than trips to school at all levels of exposure. Because the odds of JFP varied by the amount of time spent exposed on a trip to or from school, we cannot give one value for the magnitude of this difference. We can, however, estimate that the average ratio between the two was 4.19, ranging from 6.56 at 1 min to 1.81 at 16 min. In terms of the cross-cluster variance, the variation in JFP was more pronounced in trips to school (ICC = 0.513; MOR = 5.907) than trips from school (ICC = 0.445; MOR = 4.707).

Biological Sex

The results from the multilevel logistic regression models exploring the role of biological sex indicate that, for females, the OR for JFP associated with a 1-min increase in exposure was 1.19 (95% CI 1.15–1.24). For males, the corresponding OR was 1.12 (95% CI 1.06–1.19). Figure 1d shows that trips made by females had a higher likelihood of being linked to JFP at all levels of exposure than trips made by males, but the gap between the two widened with the increased level of exposure, from 2.5 times more likely at 5 min to 3.0 times more likely at 15 min. Finally, the variation in JFP was higher for trips made by males (ICC = 0.583; MOR = 7.734) than for trips made by females (ICC = 0.439; MOR = 4.617).

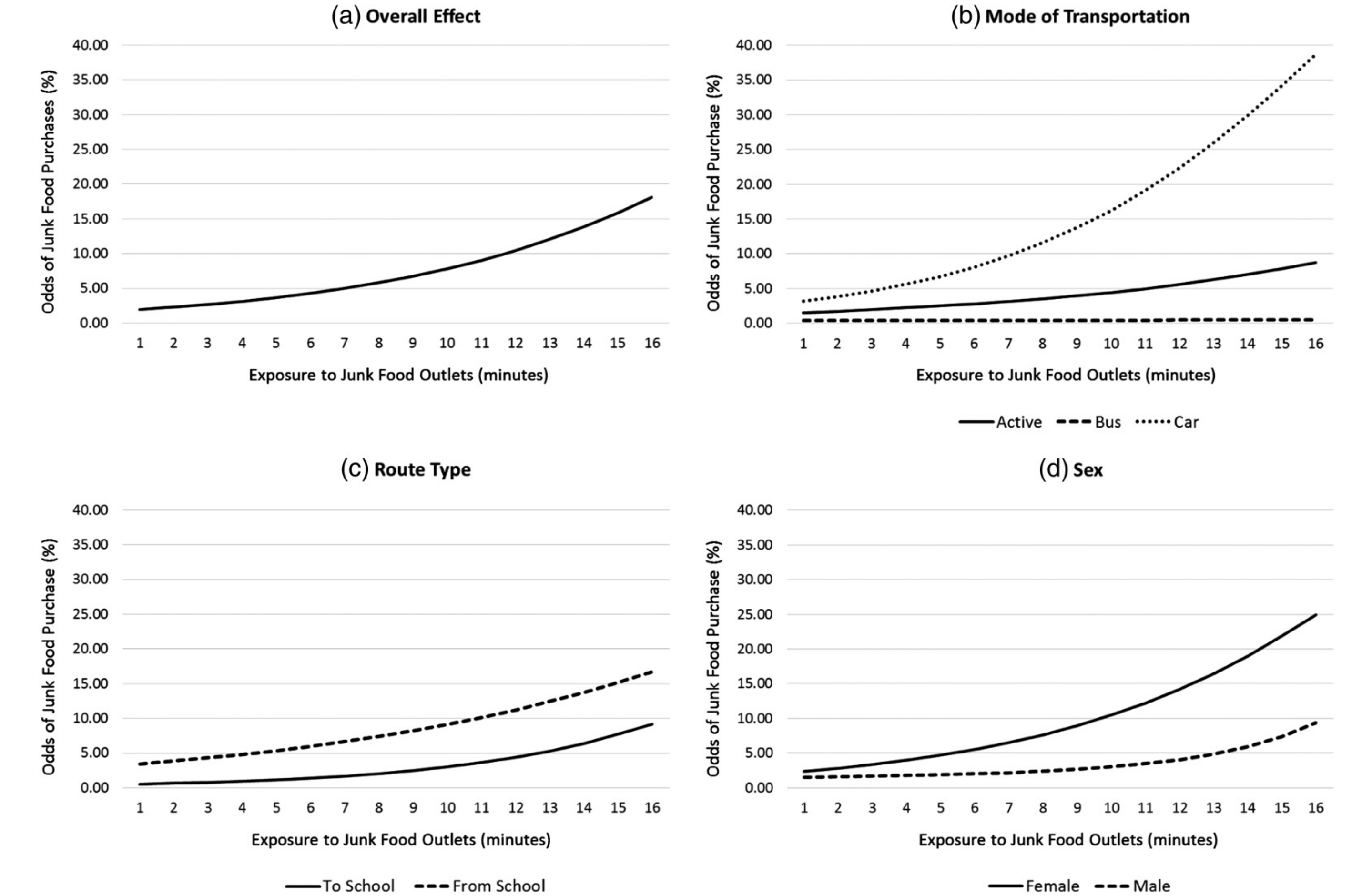

Figure 1. Effects of exposure to junk food outlets on junk food purchasing by a) overall effect; b) mode of transportation; c) trip type; and d) sex

DISCUSSION

In this study of adolescents aged 9–13 years in Middlesex-London, ON, nearly 1 in 20 trips (4.9%) made to and from school involved the purchase of unhealthy junk food. Furthermore, a significant positive relationship existed between adolescents' duration of exposure to unhealthy food outlets (i.e., fast food restaurants and variety stores) between home and school and the likelihood of JFP. This finding corroborates a previous study of adolescents in the same geographic area, which suggested that the availability or density of JFOs in a child's home or school neighbourhood increases the likelihood of junk food purchasing.[3]

While previous research has established a relationship between the presence of JFOs and purchasing/consumption,[3,5,7] such findings are inconsistent.[27] This inconsistency may be a result of using areal unit measures as proxies for exposure, which are unable to directly connect the presence of JFOs to the actual routes that adolescents take to and from school. This study has advanced a novel method to connect the GPS-derived routes of adolescents' individual trips between home and school to their junk food exposure. This is particularly important because an individual's trips and activities rarely coincide with the arbitrary spatial boundaries used in previous research (e.g., buffers, census tracts or postal codes).[3–5,13,14] Our research, therefore significantly improves upon the accuracy of daily JFO exposure among children/adolescents en route to/from school. By accurately measuring exposure to JFOs, we are able to fully understand how a child's individual and trip characteristics may alter the relationship between exposure and purchases.

Although this study found a significant relationship between exposure and purchasing, the results show considerable unexplained variance due to differences among adolescents. Exploring these differences by stratifying the data by sex, direction of trip (to or from school), and mode of travel revealed that the relationship remained significant for all categories of stratification, with the exception of adolescents who travel by bus. This lack of a relationship is due to school district policy, which prohibits children from exiting a school bus along the route to/from school before their designated stop. Any purchases would therefore be conducted only while traveling between a bus stop and home.

Conversely, not only was the relationship between exposure to JFOs and JFP positive and statistically significant for trips made by automobile, but the rate of increase in the predicted probabilities of JFP was also much steeper for trips made by automobile than for trips made by active modes (i.e., walking or biking). This finding is an important contribution to the academic literature and useful for

Table 1. Results from multilevel logistic regression models for the effects of exposure to junk food on junk food purchasing

Model		Log-odds	SE	Wald	*p*	Odds	Confidence interval	ICC	MOR
Overall effect	Intercept	−4.071	0.200	20.323	0.000	0.017			
($n = 4588$)	Exposure (β)	0.160	0.016	9.822	0.000	1.174	1.14–1.21		
	Variance (τ)	3.271	0.710	4.610	0.000			0.499	5.613
By mode of transportation									
Active	Intercept	−4.280	0.441	9.708	0.000	0.014			
($n = 1414$)	Exposure (β)	0.121	0.031	3.912	0.000	1.129	1.06–1.20		
	Variance (τ)	5.146	1.787	2.880	0.004			0.610	8.705
Bus	Intercept	−5.660	0.683	8.284	0.000	0.003			
($n = 1790$)	Exposure (β)	0.019	0.051	0.370	0.711	1.019	0.92–1.13		
	Variance (τ)	3.880	1.920	2.021	0.043			0.541	6.546
Car	Intercept	−3.612	0.319	11.322	0.000	0.027			
($n = 1384$)	Exposure (β)	0.197	0.026	7.607	0.000	1.218	1.16–1.28		
	Variance (τ)	2.786	1.087	2.564	0.010			0.459	4.914
By trip type									
To school	Intercept	−5.442	0.695	7.828	0.000	0.004			
($n = 2221$)	Exposure (β)	0.197	0.043	4.619	0.000	1.218	1.12–1.33		
	Variance (τ)	3.467	2.071	1.674	0.094			0.513	5.907
From school	Intercept	−3.449	0.208	16.591	0.000	0.032			
($n = 2367$)	Exposure (β)	0.115	0.018	6.421	0.000	1.122	1.08–1.16		
	Variance (τ)	2.637	0.658	4.007	0.000			0.445	4.707
By sex									
Female	Intercept	−3.886	0.231	16.788	0.000	0.021			
($n = 2806$)	Exposure (β)	0.174	0.019	8.951	0.000	1.190	1.15–1.24		
	Variance (τ)	2.572	0.744	3.459	0.001			0.439	4.617
Male	Intercept	−4.388	0.375	11.686	0.000	0.012			
($n = 1782$)	Exposure (β)	0.117	0.030	3.864	0.000	1.124	1.06–1.19		
	Variance (τ)	4.599	1.537	2.993	0.003			0.583	7.734

SE, standard error; ICC, intra-class correlation coefficient; MOR, median odds ratio.

the development of interventions, as it indicates that the influence of exposure on adolescents' JFP is actually greater when adolescents are driven to/from school under adult supervision than when they walk or bike. This may be a result of time-crunched parents buying food for their adolescents "on the go" and parents bending to the will of the child requesting junk food.[28] While exposure also significantly influences JFP among walkers, this should not discourage parents or public health promoters from advocating that adolescents walk to school, especially because active travel has well-known physical and mental health benefits and helps the child develop independence and a sense of environmental competence.[29]

Consistent with previous research on the built environment and adolescents' health-related behaviours,[29,30] this study revealed different patterns of behaviour along the journey to school in the morning versus the journey home from school in the afternoon. Although the effect of exposure was significant for trips in both directions, the odds of JFP by adolescents were much higher on the journey home from school versus to school, and the odds narrowed the longer a child travelled. This finding is likely related to the adolescent having more flexible time on the way home after school compared with the morning, when he or she has to reach school for a set time; it could also be due to daily eating patterns and adolescents just being hungrier after a long school day.

Analysis revealed that females were more strongly influenced by exposure to JFOs than males, being between 1.6 and 3.5 times more likely to make a JFP. Trips made by females had a higher likelihood of being linked to JFP at all levels of exposure than trips made by males. The gap in the likelihood of JFP between trips by females and males widened with the increased level of exposure. This finding is consistent with a previous study of adolescents in London, ON, which found that females were 1.5 times more likely than males to have self-purchased (without parents) fast food at least once per week.[3] It is unclear why the females in our study were more likely to purchase junk food and were more influenced by exposure. Females may have greater access to their own spending money, as it is common in Canadian culture for adolescent girls to start earning money earlier through babysitting.[31]

Limitations

Although this study offers a significant advance by using objective methods of observing adolescents' actual routes between home and school to assess direct JFO exposure, some limitations exist. Researchers have cautioned that even GPS data can have limitations, as they track only where the child has travelled over the course of data collection and may not encompass the totality of their potential exposure.[19] Chaix et al.[12] argue that biases related to selective daily mobility may prohibit accurate assessment of environmental effects. To limit the potential burden on research subjects, most studies using GPS tracking limit data collection to short periods (typically one week); it can be argued that one week of tracking spatial behaviours is not enough time to assess how potential environmental exposures may affect chronic diseases (e.g., obesity, type 2 diabetes, cancer). Nevertheless, it can be argued that GPS tracking can be an ideal tool for assessing how exposure to environmental features such as JFOs influences the likelihood of making a JFP (often an impulse activity).

CONCLUSION

This is one of the first studies to empirically establish a relationship between objective, GPS-derived measurement of direct JFO exposure and adolescents' JFP. While causal relations cannot be inferred and the data are not necessarily generalizable to other age groups or geographic settings, the study highlights important implications for municipal planners, school board officials and other decision-makers involved in the regulation, development and management of adolescents' environments. In particular, municipalities should embed specific bylaws and policies restricting the concentration of JFOs close to schools, as passed in London, UK.[32] School board officials should also consider potential JFO exposure when making decisions on the siting of new schools and the closing of existing neighbourhood schools, which typically results in longer average commutes for students and greater exposure to JFOs. Furthermore, public health agencies at all levels (i.e., municipal, provincial and federal) should work together, in concert with municipal economic development organizations (e.g., business improvement areas) and private sector stakeholders on the supply side of the food system (e.g., food producers, restaurant owner associations, retailers) to introduce effective economic incentives to encourage greater availability, visibility and knowledge of healthier food options in local food stores and restaurants.

In addition to highlighting the need to reduce junk food exposure in neighbourhood food environments, we also reiterate what other studies have shown about the importance of parents as role models for their adolescents when it comes to healthy eating.[33] The findings indicate that junk food exposure has the greatest impact on JFP when adolescents are being driven in a car (i.e., being accompanied by an adult). This finding points to the need for further education to improve food literacy regarding overconsumption of generally unhealthy fast food. Nevertheless, public health practitioners and researchers should not single out adolescents as inherently poor decision-makers; we cannot forget how common junk food consumption is across North American society. Like their adult counterparts, adolescents report eating junk food because of the convenience and taste.[33] Furthermore, "to give up eating what teens call 'junk food' would be to give up much more than the food itself. This speaks to the importance of changing social norms around healthful eating." (p. S42)[34] Thus, we need to continue to make it easier and more attractive to eat healthily; this is an area where food "apps" for smartphones have proven to be effective at behaviour change.[35] Given the immediate and long-term health issues associated with poor dietary habits among adolescents, it is imperative that more innovative research be conducted on how to ameliorate the negative impacts of junk food exposure in adolescents' environments, particularly strategies and interventions that promote lifelong healthy behaviours.

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RÉSUMÉ

OBJECTIFS : Examiner l'influence de l'exposition des adolescents aux points de vente d'aliments malsains sur leurs achats d'aliments vides durant le trajet entre l'école et la maison, et en particulier à la façon dont l'exposition et les achats diffèrent selon le sexe biologique de l'enfant, le moyen de transport et le sens du trajet.

MÉTHODE : Entre 2010 et 2013, des élèves (*n* = 654) de 9–13 ans fréquentant 25 écoles du comté de London-Middlesex, ON, ont rempli un questionnaire sociodémographique et un journal de leurs activités (pour repérer leurs achats d'aliments), et ont été observés pendant deux semaines par un système mondial de localisation (pour suivre leurs trajets entre l'école et la maison). Les données spatiales sur les itinéraires et les données d'achat ont été intégrées à une base de données validée de points de vente d'aliments dans un système d'information géographique; l'exposition a été mesurée selon le nombre de minutes qu'un enfant passait à moins de 50 m d'un point de vente d'aliments malsains (p. ex., restaurants rapides, magasins à prix uniques). Pour les trajets où les enfants étaient exposés à des aliments vides (*n* = 4588), nous avons procédé par régression logistique multiniveau pour évaluer la relation entre l'exposition et l'achat.

RÉSULTATS : Les analyses multiniveaux ont montré que la durée d'exposition des adolescents aux points de vente d'aliments malsains sur le chemin de l'école avait un effet significatif sur leur probabilité d'achat d'aliments vides. Cette relation est demeurée significative lorsque les données ont été stratifiées selon le sexe (fille/garçon), le sens du trajet (vers l'école/vers la maison) et le moyen de transport (transport actif/automobile), sauf pour les adolescents se déplaçant en autobus.

CONCLUSION : Les politiques et les programmes qui atténuent la concentration des points de vente d'aliments malsains près des écoles sont essentiels pour encourager les comportements alimentaires sains chez les enfants et pour réduire les problèmes de santé liés à l'alimentation, comme l'obésité.

MOTS CLÉS : milieu bâti; environnement alimentaire; systèmes d'information géographique; achat d'aliments; régime alimentaire; enfant; adolescent