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The impact of children's exposure to greenspace on physical activity, cognitive development, emotional wellbeing, and ability to appraise risk

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ABSTRACT

Introduction: The current study utilised objective techniques to investigate the relationship between children's time spent in greenspace (open land covered in grass or other vegetation) with various physical and psychological variables. Potential relationships between physical activity and greenspace with body composition, emotional wellbeing, sensation seeking tendencies, ability to appraise risk, and cognitive development are investigated.

Methods: 108 participants aged 11–14 years from three intermediate schools in Auckland, New Zealand, were assessed. Moderate-to-vigorous physical activity (MVPA) and geolocational data were recorded using accelerometers and portable global positioning system (GPS) receivers (respectively) over a 7-day period in September-December 2014. Body mass index (BMI) and waist-to-height ratio (WHtR) were calculated from height, weight, and waist circumference. Participants also completed online cognitive testing, a computerised risk appraisal tool, and a questionnaire for assessing emotional wellbeing and sensation seeking characteristics. Data analysis took place during February to May 2015. Generalised linear mixed models were used to quantify the associations between MVPA, greenspace exposure, and secondary outcome variables.

Results: Findings confirmed that greenspace exposure is positively associated with MVPA in children ($B=0.94$; $p<0.05$). Furthermore, both greenspace exposure and MVPA were related to greater emotional wellbeing, with the former exhibiting a stronger relationship than the latter. Risk-taking and sensation seeking scores were positively associated with MVPA, but not with greenspace exposure. No associations were detected between BMI, WHtR, cognitive domains, and either MVPA or greenspace exposure.

Conclusions: Findings support the theory that for children, greenspaces are an important environmental influence on physical activity and emotional wellbeing.

1. Introduction

Physical inactivity in children has been identified as a significant and growing public health concern (W.H.O. Atlas, 2015). Regular moderate-to-vigorous physical activity (MVPA) in children is associated with numerous benefits, including improved cardiovascular health, reduced indicators of metabolic syndrome, improved musculoskeletal health, reduced risk of type 2 diabetes, and lesser symptoms of depression and anxiety (Janssen and LeBlanc, 2010). A growing body of research has investigated environmental influences on children's physical activity (Sallis et al., 2008; Cervero and Kockelman, 1997; Lovasi et al., 2011). In particular, this body of research has highlighted that greenspace provides an activity and health promoting environment (Wolch et al., 2010; Fjørtoft and Sageie, 2000; Ord et al., 2013). Greenspace is commonly defined as any open piece of land that is publically accessible and is partly or completely covered with grass, trees, or other vegetation (United States Environmental Protection Agency, 2014). Research on greenspace has generally found a positive correlation between time spent in greenspaces and children's physical activity (Lachowycz and Jones, 2011).

Recent technological improvements have enabled the collection of objective, high-resolution data on children's greenspace exposure. One such study used portable Global Positioning System (GPS) receivers and accelerometers to record positional and activity data from children during their free time (Almanza et al., 2011). This study found that children were 34–39% more likely to engage in MVPA when in greenspaces compared to non-

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greenspaces. A different research group, using the same technology found that children were 37% more likely to engage in MVPA when in a greenspace compared to non-greenspace (Wheeler et al., 2010). This particular study found that children only spent 2% of their after school time in greenspaces, however that this environment accounted for 9% of MVPA for boys and 6% of MVPA for girls.

A different body of research suggests that physical activity and greenspace exposure may be independently associated with other important aspects of childhood development, such as cognitive function, emotional wellbeing, and propensity towards risk-taking (Janssen and LeBlanc, 2010; Tomporowski et al., 2008; Wells, 2000; Faber-Taylor et al., 2002; Bonhauser et al., 2005; Nelson and Gordon-Larsen, 2006). The research linking children's greenspace exposure and cognitive development mostly consists of small, exploratory studies; however, this literature suggests positive associations exist between greenspace exposure and attentional capacity (Wells, 2000; Faber-Taylor et al., 2002). Furthermore, a literature review in 2008 concluded that there is a positive association between children's physical activity levels and their executive function (Tomporowski et al., 2008).

With regard to the relationship between physical activity and emotional health in children, observational studies have generally reported small to modest associations between physical activity and depressed mood (Janssen and LeBlanc, 2010). In contrast, experimental research has tended to report beneficial effects of exercise interventions on the symptoms of both anxiety and depression (Bonhauser et al., 2005; Norris et al., 1992; Annesi, 2005). Greenspace exposure has also been associated with greater emotional wellbeing in children, as indicated by lower self-rated measures of emotional distress found in children living in 'greener' neighbourhoods (Wells and Evans, 2003). However, conversely, a large survey of Canadian children found no consistent relationships between neighbourhood greenspace and emotional wellbeing (Huynh et al., 2013).

Theorists have also proposed an association between time spent in greenspace and the formation of healthy attitudes towards risk-taking (Louv, 2005). However, there has been no empirical research to test this hypothesis. Similarly, the associations between children's physical activity levels and their propensity to take risks has received very little research attention. A single study reported that children who participated in a wide range of sporting activities had lower self-reported levels of high-risk behaviours; however, this effect was highly mediated by parental involvement in sports activities (Nelson and Gordon-Larsen, 2006).

The current study seeks to address the aforementioned research gaps by combining accelerometry, GPS, and geographic information systems (GIS) to provide objective, high-resolution information on children's physical activity and location. Building on other studies that have used this methodology (Almanza et al., 2011; Wheeler et al., 2010), we add direct and validated measures of cognitive development, emotional wellbeing, and risk-taking behaviour. This methodology allows quantitative analysis of the relationship between greenspace exposure and physical activity, as well as enabling investigation into other important variables which contribute to healthy childhood development.

2. Methods

2.1. Participants

Recruitment for this study commenced with invitations to participate being made by the researchers to intermediate schools in Auckland, New Zealand. Schools were chosen to represent culturally, socioeconomically and geographically diverse neighbourhoods. Nine schools were approached and three agreed to participate. Although these schools cover geographically distinct and culturally diverse regions of Auckland, only middle to higher decile neighbourhoods were represented by the three participating schools. Intermediate schools cover the school years 7 and 8, which include children aged between 10 and 14. This age group was targeted by this study as previous research has shown that children in this age group exhibit a decrease in physical activity which continues into adolescence (Kimm et al., 2000; Troiano et al., 2008). Greater exposure to greenspace may provide a means of counteracting this trend. A total of 118 participants (46 boys, 66 girls) aged 11–14 years consented to participate in the study. Inclusion criteria included: 1) students enrolled in school years 7 or 8, 2) appropriate English language comprehension. Exclusion criteria included: 1) physical disability that impaired mobility, 2) cognitive impairment likely to affect the ability to complete testing. Written informed consent was obtained from the parents/guardians of all participants, and assent forms were signed by all participants. Ethical approval for this study was obtained by the Auckland University of Technology Ethics committee.

2.2. Measures

2.2.1. Greenspace exposure

Locational data were gathered using the Qstarz BT-Q1000XT GPS receiver (Qstarz International, http://www.qstarz.com, Taipai, Taiwan) which was worn on a waist belt during the monitoring period and configured to record data every 15 s. The accuracy and suitability of these devices has been established in previous research (Duncan et al., 2013; Schipperijn et al., 2014). Due to limited availability of these devices, 78 participants were fitted with a GPS receiver. Participants were given verbal and written instructions regarding use of the device and a diary to record non-wear time. They were instructed to wear the device as much as possible during waking hours but asked to remove the device for sleeping, bathing, and water based activities. They were given charging devices and instructed to recharge the devices every night while they slept, a routine that has been used successfully in similar research (Kerr et al., 2011). At the initial fitting of the device it was turned on and adhesive tape placed over the 'on/off' toggle to ensure that the device remained on and in recording mode throughout the duration of the seven-day monitoring period.

2.2.2. Physical activity

Physical activity frequency, duration, and intensity were measured using the Actigraph GT3X+ accelerometer (Actigraph, http://www.actigraphcorp.com, Pensacola, FL). These devices were configured to sample activity at 30 Hz that was aggregated into 15 s epochs. The accuracy and acceptability of these devices have previously been validated for use with children in physical activity research (Evenson et al., 2008; Trost et al., 2011). All 118 participants were fitted with accelerometer devices. These were also worn on the supplied belt above the right iliac crest and verbal and written instruction on correct use of the device was given similar to the GPS receiver. Activity intensity was classified as sedentary, light, moderate, or vigorous according to the Evenson cut-points (Evenson et al., 2008) which have been previously validated against both indirect calorimetry and other accelerometer devices (Trost et al., 2011).

2.2.3. Physical measures

The standing height of each participant was measured to the nearest millimetre with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia), and weight was measured to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was then calculated as weight (kg) divided by squared height (m^2). In addition, waist circumference measurements were made at the highest point of the iliac crest at minimal respiration, and the waist to height ratio (WHtR) was calculated.

2.2.4. Emotional wellbeing

Wellbeing was assessed with three different self-report measures. The Life Satisfaction Scale (LSS) is a 5-item questionnaire derived from Hubener's Student Life Satisfaction Scale (Huebner, 1991). Participants also completed the Ten Domain Index of Wellbeing (TDIW) which asks the participant to rate their happiness in ten different life domains on a scale from 0 to 10, which are then summed to give an aggregate wellbeing score between 0 and 100 (Rees et al., 2010). Lastly we included a single item measure of happiness with life as a whole (HS) measured on a scale from 0 to 10. These three scales have been used in large research projects in this age group in England and all have been shown to exhibit good levels of reliability and stability (Rees et al., 2010).

2.2.5. Sensation seeking

Sensation seeking is a personality trait characterised by the need for varied, novel, and complex sensations and experiences, and the willingness to take physical and social risks for such experiences (Zuckerman, 1990). This was measured using the Short Form Sensation Seeking Scale (SFSSS) (Zuckerman, 1990). This scale consists of four items which relate to the four domains of sensation seeking (disinhibition, experience-seeking, boredom susceptibility, and thrill-seeking). In research with 5000 children aged 11–15, scores on the SFSSS were found to correlate well with the results of a more comprehensive and well validated 40 item scale (Stephenson et al., 2003; Zuckerman et al., 1978). SFSSS scores were also found to correlate with established risk-taking behaviours such as illicit drug use (Stephenson et al., 2003). Of the 118 participants in the study 116 completed the questionnaire instrument wellbeing correctly.

2.2.6. Risk-taking

Risk-taking behaviour was assessed using the youth version of the Balloon Analogue Risk Task (BART-Y), a computer-based behavioural measure designed to reflect elements of risk-taking present in the natural environment (Lejuez et al., 2007). The BART-Y has been shown to correlate with real world risk-taking behaviours in adolescents (Lejuez et al., 2002, 2007). Using a behavioural measure of risk-taking avoids the limitations of self-report measures which may arise from perceived negative consequences of reporting risky behaviour and possible lack of insight into their risk-taking (Lejuez et al., 2007).

2.2.7. Cognitive development

Computerised neurocognitive testing was conducted using CNS Vital Signs (CNS-VS, www.cnsvs.com), a web-based battery of seven tests that are frequently used in neuropsychological analysis and have well-established reliability and validity (Gualtieri and Johnson, 2006). From the results of these tests, CNS-VS calculates the subject's performance in the following cognitive domains; visual memory, verbal memory, processing speed, psychomotor speed, reaction time, cognitive flexibility, and executive function. The results of the CNS-VS test battery have been shown to correlate highly with conventionally administered neurocognitive testing and also show good levels of test-retest reliability in participants aged from 7 to 90 (Gualtieri and Johnson, 2006). CNS-VS automatically removes invalid scores due to incorrect test performance. Out of all the domain scores recorded by all participants 92% were rated as valid by the application and thus were included in the analysis.

2.3. Procedures

Data collection for this observational study took place during Spring, (between 9th September and 1st December 2014). Students completed surveys, performed computerised testing, and had physical measures taken by a trained research assistant. They were then fitted with a GPS and accelerometer device to wear for the next seven-day period and given an activity diary to fill in over this time. At the conclusion of the monitoring period, the devices and diaries were collected from participants.

2.3.1. Data processing

GPS data and accelerometer data were combined using the Personal Activity Location Measurement System (PALMS) which uses the time stamps of both devices to merge both sets of data. The output from the PALMS software contains a record of the participants' location every 15 s and the intensity of movement at that location. Data points without matching time stamps from both the GPS and accelerometer are excluded from the analysis by the PALMS application (National Cancer institute, 2015). Non-wear time, defined as 60 min of consecutive zero activity counts, was removed from the data (Oliver et al., 2011). The inclusion criterion for the 78 sets of merged GPS-accelerometer data was that each participant had at least three days of data collected with a minimum of four hours of valid data on each day. These criteria have been used in previous research of a similar nature (Almanza et al., 2011). This resulted in exclusion of six files from the analysis, leaving 72 combined activity and location files; an inclusion rate of 92%. There were also a further 40 accelerometer files without matching GPS data. These accelerometer files were included in the analysis provided that at least 10 h of data had been gathered per day for a minimum of five days of the monitoring period. These inclusion criteria were adopted from previous research into children's physical activity (Oliver et al., 2011). Of the 40 unmatched files, 36 met these criteria. This gave us a total dataset of 108 accelerometer files and 72 merged GPS and accelerometer files. The overall inclusion rate was 91.5%. In total 8404 h of data was included in the analysis, consisting of 5422 h of merged GPS and accelerometer data and 2982 h of additional accelerometer data. The merged data streams retrieved from PALMS were imported into GIS for spatial analysis using ArcGIS software. (ESRI ArcMap 10.2.1) (Fig. 1).

2.4. Data analysis

Data analysis took place during February to May 2015. GIS mapping of the GPS data against the parks dataset available through Open Street Map (www.openstreetmap.org) allowed the identification of time points located within publically accessible parks, sports fields, and reserves. This dataset does not contain information on other land areas that would also be categorised as greenspace such as accessible vacant land or school playgrounds. It also lacked the resolution to be able to categorise backyards as greenspaces as has been done in other research (Wheeler et al., 2010). This dataset was chosen due to a lack of a more comprehensive resource covering the Auckland region. The percentage of total data points inside greenspaces for each participant was calculated. Indoors and outdoors activity locations were differentiated by the signal to noise ratio (SNR) detected by the GPS device. In outdoor locations GPS satellite signals are stronger and therefore SNR will be higher. The PALMS application was set to mark data points with a SNR > 250 as occurring outdoors. This criterion has been shown to be valid and reliable in previous research on both adults (Kerr et al., 2012) and children (Tandon et al., 2013). Four independent generalised linear mixed model (GLMM) structures were used to quantify the relationships among the measured variables while accounting for variations in the data

Fig. 1. An example of data collected from one greenspace and surrounds, showing participants GPS locations and intensity of physical activity.

from both fixed and random effects. All models specified child nested within school as a random effect.

Model 1: Each of the outcome variables (emotional wellbeing, cognitive domain scores, risk-taking, sensation seeking, and physical health measures) were entered (individually) as fixed effects in a series of GLMMs with the percentage of time spent in greenspace as the dependent variable and sex, age, and school included as covariates.

Model 2: Identical structure to Model 1 with the exception of percentage of time spent in MVPA entered as the dependent variable.

Models 3 and 4: Repetition of Models 1 and 2 with percentage of time spent in MVPA (Model 3) and greenspace (Model 4) entered as fixed effects.

The latter two models were included to investigate the relative strength of the effects of MVPA and greenspace exposure on the outcome variables. All analyses were conducted using SPSS software (SPSS v22).

3. Results

Of the 118 participants, valid accelerometer data were collected from 108, and valid GPS data from 72 participants. Table 1 displays the descriptive statistics relating to the participants who supplied both GPS and accelerometer data.

There were slightly more female (59%) participants, and the average age was 12.66 years. Over the course of the week on average participants spent 1.17% of monitored time in greenspace which equated to 16.3 min per day. Male participants spent 1.53% of their monitored time in greenspace compared to 0.9% for females, a difference that was not significant ($p=0.090$). Separate analysis of the outdoors data points found that males spent 4.90% of their outdoor time in greenspace compared to females who spent an average of 2.27% in greenspace. This difference was however not significant ($p=0.054$). Overall the average daily time in MVPA was 42.48 min, which was 7.77% of the monitored time. Males spent a greater proportion of time in MVPA, with an average of 49.08 min/day in MVPA, compared to 37.47 min/day for Females ($p=0.008$). Only 27.3% of males and 15.6% of females in this study met the New Zealand Ministry of Health guidelines of 60 min of MVPA per day (Ministry of Health, 2015). Despite the relatively low proportion of time spent in greenspace, mean activity counts per epoch were much higher during time in greenspace (282) compared to non-greenspace readings (51) ($p=0.002$). Results also indicated that 7.07% of total weekly activity counts occurred

Table 1
Descriptive statistics for participants with combined GPS and accelerometer data.

			Male ($n=31$)	Std Dev	**Female ($n=41$)**	Std Dev	**All ($n=72$)**	Std Dev
Age	Mean	Years	12.65	0.54	12.66	0.51	12.66	0.51
BMI	Mean		18.97	2.76	19.72	3.39	19.40	3.01
WHtR	Mean		0.44	0.04	0.43	0.05	0.43	0.04
Time in Greenspace	Total over study period	Mins	144.29	192.70	91.66	120.67	114.32	154.62
% total time in greenspace			1.53%	1.87%	0.90%	1.24%	1.17%	1.54%
% of outdoor time in greenspace			4.90%	9.03%	2.27%	2.67%	4.00%	7.12%
Total time in	Sedentary		3084.95	842.80	3061.25	931.41	3071.45	876.01
	Light		1171.73	332.66	1046.46	342.93	1100.40	337.21
	Moderate		231.48	76.75	186.56	75.43	205.90	77.63
	Vigorous		177.39	96.60	112.77	66.83	140.59	85.39
	MVPA		408.87	156.65	299.33	130.05	346.49	149.18
Avg MVPA/day			49.08	17.90	37.47	15.62	42.48	26.00
% time in MVPA			8.82%	2.76%	6.98%	2.79%	7.77%	2.87%

during the 1.17% of time in greenspace.

The results of the four generalised linear mixed models are displayed in Table 2. Each model shows the associations between each of the outcome variables against; percentage of monitored time in greenspace (column 1); percentage of monitored time in MVPA (column 2); time in greenspace adjusted for MVPA (column 3); and time in MVPA adjusted for greenspace exposure (column 4).

None of the models showed significant relationships between the independent variables and measures of cognitive development (not included in Table 2). In each column of Table 2, the Beta coefficient (β) indicates the absolute change in each outcome variable for a 1% change in either greenspace exposure or time spent in MVPA. In Model 1, a significant relationship was detected between percentage of time in greenspace and the percentage of time in MVPA ($B=0.951$; $p=0.000$). Likewise, there were positive relationships between the proportion of time spent in greenspace and all three measures of emotional wellbeing (LSS $\beta=0.861$, $p<0.001$; TDIW $\beta=3.176$, $p<0.001$; HS $\beta=0.445$ $p<0.001$). However, there were no significant relationships with any physical, risk-taking, or sensation seeking measures. In Model 2, the percentage of time in MVPA was significantly associated with all measures of emotional wellbeing (LSS $\beta=0.528$, $p<0.001$; TDIW $\beta=2.561$, $p<0.001$; HS $\beta=0.225$, $p<0.001$), as well as risk-taking ($\beta=1.098$, $p<0.045$) and sensation seeking ($\beta=0.402$, $p<0.001$) scores. There were no associations between MVPA and either BMI or WHtR. In Model 3, the strength of the associations between greenspace and emotional wellbeing were reduced but still significant (LSS $\beta=0.661$, $p<0.001$; TDIW $\beta=2.670$, $p<0.001$; HS $\beta=0.363$, $p<0.001$). In Model 4, a significant association remained between one of the measures of emotional wellbeing – life satisfaction - (LSS $\beta=0.181$, $p=0.042$), but not the other two - ten domain of wellbeing, or happiness with life - (TDIW $\beta=0.397$, $p=0.415$; HS $\beta=0.038$, $p=0.466$). Furthermore, the association between MVPA and both risk-taking and sensation seeking present in Model 2 was not found in Model 4.

4. Discussion

This study builds on the existing body of research which has utilised objective measures of children's physical activity and greenspace exposure (Almanza et al., 2011; Wheeler et al., 2010) by including validated measures of cognition, emotional wellbeing, sensation seeking, and risk-taking. This approach enabled analysis of several relationships that have not been previously investigated, such as the relative effects of greenspace and physical activity on emotional wellbeing and the hypothesized association between risk-taking and greenspace exposure.

On average, children in this sample only spent 1.17% of monitored time in greenspaces. These low amounts of exposure to greenspaces are commensurate with previous research findings. For example, a study from the UK found that children spent 2% of their afterschool time in greenspaces (Wheeler et al., 2010). On average participants in the current study spent 17.9 min of monitored time in greenspace during weekdays compared to 12.2 min during weekend days, difference that was non-significant ($p=0.053$). Other research has found that children spend an average of 11.9 min of afterschool weekday time, and 18.6 min of weekend days in greenspaces (Lachowycz et al., 2012). Nonetheless, despite this low level of exposure to greenspaces, they remain an important environmental context for physical activity with 7.07% of all activity counts taking place in greenspace. Mean accelerometer count per epoch in greenspace was 282 compared with 51 in non-greenspace, a large, significant difference of 231 counts. This provides further support for the theory that

Table 2
Generalised linear mixed models of relationships between greenspace exposure, time in MVPA, and independent variables.

	Model 1: Greenspace exposure			Model 2: Percentage time in MVPA			Model 3: Greenspace exposure adjusted for MVPA			Model 4: MVPA adjusted for greenspace exposure		
	Beta	95% CI	p value	Beta	95% CI	p value	Beta	95% CI	p value	Beta	95% CI	p value
Time in MVPA (%)	**0.951**	**0.467–1.435**	**< 0.001**									
Life satisfaction score	**0.861**	**0.458–1.264**	**< 0.001**	**0.528**	**0.330–0.726**	**< 0.001**	**0.661**	**0.368–0.955**	**< 0.001**	**0.181**	**0.006–0.355**	**0.042**
Happiness score	**0.445**	**0.177–0.713**	**0.001**	**0.225**	**0.113–0.338**	**< 0.001**	**0.363**	**0.171–0.554**	**< 0.001**	0.038	−0.065 to 0.141	0.466
Ten Domain Index of wellbeing score	**3.176**	**1.487–4.865**	**< 0.001**	**2.561**	**1.750–3.372**	**< 0.001**	**2.67**	**1.290–4.050**	**< 0.001**	0.397	−0.569 to 1.362	0.415
Waist/height ratio	−0.001	−0.007 to 0.004	0.586	−0.002	−0.005 to 0.001	0.253	−0.006	−0.012 to 0.001	0.089	0.002	−0.003 to 0.008	0.386
Body mass index (kg/m^2)	−0.232	−0.586 to 0.122	0.194	−0.197	−0.407 to 0.014	0.067	−0.312	−0.798 to 0.174	0.204	0.135	−0.280 to 0.549	0.518
Risk taking score	0.091	−1.812 to 1.994	0.924	**1.098**	**0.024–2.173**	**0.045**	0.298	−1.781 to 2.378	0.774	−0.187	−1.411 to 1.037	0.760
Sensation seeking score	−0.023	−0.426 to 0.380	0.910	**0.402**	**0.199–0.606**	**< 0.001**	0.125	−0.211 to 0.461	0.461	−0.027	−0.192 to 0.137	0.741

Boldface indicates statistical significance ($p<0.05$).

greenspace provides a supportive environment for increased MVPA and underscores the value of greenspace exposure in children's health promotion initiatives.

This study found a strong positive relationship between the proportion of time spent in greenspace and the proportion of time in MVPA: for every 1% increase in time in greenspace there was a 0.95% increase in MVPA. This finding is consistent with the majority of previous research in the field, although differences in measurement and analysis of variables make it difficult to directly compare results. A previous study found that each hour of time outdoors was associated with a 27 min/week and 21 min/week increase in MVPA for boys and girls respectively (Cleland et al., 2008). However, this study did not measure time in greenspace specifically. Previous studies using similar methodology have reported that children were 34% (Almanza et al., 2011) or 37% (Wheeler et al., 2010) more likely to engage in MVPA when in a greenspace. The current research supports the hypothesis that greenspaces are highly supportive of increased physical activity.

A notable finding was that a child's level of greenspace exposure had a significantly stronger relationship with emotional wellbeing than their physical activity level. Indeed, each additional 1% of time spent in greenspace was associated with a 0.66 increase in life satisfaction score; by comparison, a 1% increase in MVPA was associated with a 0.18 increase in life satisfaction score. Furthermore, the Happiness and Ten Domain Index of Wellbeing scores were both significantly related to greenspace exposure, but not to physical activity. Previous studies have identified independent links between physical activity and emotional wellbeing, and between greenspace exposure and emotional wellbeing (Annesi, 2005; Wells and Evans, 2003). However, this study is the first to be able to differentiate the individual effects of greenspace and physical activity on wellbeing. These findings increase our understanding of the variables that contribute to children's emotional wellbeing and have implications for interventions aiming to increase flourishing in children.

In addition, we found that the proportion of time spent in MVPA was significantly related to both sensation seeking and risk-taking behaviour. This suggests that, as had been previously demonstrated in adolescent populations (Sallis et al., 2000), children who have an innate affinity for novelty, excitement, and risk-taking are drawn towards physically active pursuits. Interestingly, no relationships were observed between greenspace exposure and either risk-taking or sensation seeking. From this data it seems that children higher in sensation seeking or risk-taking are not more likely to seek out greenspaces as an environment conducive to novel experiences and risky behaviour.

We found no significant relationships between any of the physical measures taken (BMI and WHtR) and either MVPA or greenspace exposure. Previous studies that have investigated the relationships between children's physical activity levels and their BMI have generally reported either no relationship (Almanza et al., 2011), or small but significant relationships between these variables (Wheeler et al., 2010; Ekelund et al., 2004; Trost et al., 2003). Possibly the failure to detect any associations between these variables is a reflection of the fact that the sample population was relatively homogenous and almost entirely of children of healthy weight. Additionally, no relationships were found between any of the cognitive measures and either greenspace exposure or average daily MVPA. While the existing research between these variables has yielded contradictory results, most of the positive relationships reported have either been from non-peer reviewed studies (Sibley and Etnier, 2003), or found only weak correlations (Carlson et al., 2008; Lees and Hopkins, 2013; Tomporowski et al., 2008). An existing body of research suggests that one means by which exposure to greenspaces may foster cognitive ability is through restorative effects on children's attentional capacity (Bagot et al., 2015; Berman et al., 2008). However, the current study did not employ a methodology that was able to measure this effect. More research on larger populations is needed to investigate the possible associations between physical health, cognitive development, and greenspace exposure.

A strength of the current study was the use of objective measures of physical activity and greenspace exposure. Results presented here add to the growing body of work that attempts to characterise the location of children's physical activity using advanced monitoring techniques. In addition, the study utilised well-validated, direct measures of cognitive development and risk-taking behaviour, and validated survey instruments for the measures of emotional wellbeing. The sample included three different schools from geographically diverse neighbourhoods, and the students included covered a wide range of ethnicities, enhancing the generalisability of the results.

Several study limitations are noted however. Firstly, the sample size of 108 participants was relatively small and of this sample only 72 participants provided both GPS and Accelerometer data. It is possible that there were meaningful associations that were not detected due to lack of statistical power. Secondly, all data were collected during term time from September to December 2014, and thus no conclusions can be drawn about seasonal variations in greenspace exposure or physical activity. Finally, the observational design of the study precludes any ability to infer causation from the findings.

Greater exposure to greenspace has been proposed as a variable which may positively influence physical activity in both adults and children. This study reinforces previous research findings showing that greenspace exposure is associated with higher levels of MVPA in children. We also found an association between both risk-taking behaviour and the personality trait of sensation seeking and engagement in MVPA. Emotional wellbeing was positively associated with both physical activity and greenspace exposure. However, this study found that children's emotional wellbeing was more strongly related to greenspace exposure that it was to their physical activity. These findings further underscore the importance of time in greenspaces as a component of an emotionally healthy childhood. Although this study is unable to determine any causative relationship between variables, promotion of time spent in greenspace may be an effective means of increasing children's physical activity levels and emotional wellbeing.

Conflict of interest

The authors of this document declare that there are no conflicts of interest.

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