DOES WALKING OR CYCLING PROVIDE THE LOWEST $PM_{2.5}$ AIR POLLUTION DOSE DURING THE TRIP FROM HOME TO SCHOOL FOR CHILDREN?

Matthew D. Adams, Scott A. Bennet, Niko Yiannakoulias & Pavlos Kanaroglou

McMaster University

Introduction

Air pollution is associated with many negative health effects in children that include reduced lung function (Brunekreef et al., 1997; Gauderman, 2000; Wallner et al., 2012), lung development (Gauderman et al., 2004), cognitive performance (Hutter et al., 2013; Suglia et al., 2008) and function (Freire et al., 2010). See Wong et al. (2003) for a meta-analysis of health benefits attributed to reduced air pollution exposure in children. A large body of research also indicates a relationships between air pollution and asthma induced hospital admissions (Wong et al., 2003).

Most research examining the effects of air pollution on health are observational studies that use ambient air pollution concentrations as the exposure metric (Heck et al., 2013; Jerrett et al., 2007; Moridi et al., 2013; Urman et al., 2013). Ambient conditions are variable and can be affected by many factors, for example, ambient air pollution exposure can change because of transportation mode choice (Panis et al., 2010; Zuurbier et al., 2009), and personal vehicles' air pollution concentrations may be higher (Gulliver and Briggs, 2004) or less than (Briggs et al., 2008) the surrounding ambient conditions. More recent studies have incorporated activity patterns when estimating exposure to improve accuracy (Baxter et al., 2013; Buonanno et al., 2013). Dose, based on the volume of air consumed and the ambient conditions may be an improvement over using only ambient conditions, because it accounts for changes in respiration rate due to changes in activity level. As a person increases their intake of air, they will haveincreased exposure to pollution. This is particularly important when comparing active transportation modes, as we are, because when a person engages in strenuous activity their respiration rate increases to obtain more oxygen, which results in higher doses of air pollution as they inhale a higher amount of total air.

In the Greater Toronto and Hamilton Area more than half of the car trips taking students to school are single purpose trips (Metrolinx, 2011), active transportation would negate the need for these trips to occur resulting in reduced vehicle pollution emissions. One-quarter of all those trips were made by an adult who acknowledged that the distance is suitable for walking (Metrolinx, 2011). A current problem with active transportation is the lack of separated infrastructure, which results in people participating in active transportation along or adjacent to passenger vehicles; thus, people who are engaged in active transportation are exposed to the pollutants caused by those who are not.

In our paper, we compare air pollution exposure, determined as dose, for children during their trip from home to school between walking and cycling. This non-discretionary trip occurs for students between September and June (inclusive), in Hamilton, Ontario, Canada. We identify if either mode results in a lower dose of air pollution. For this analysis, we apply air pollution concentrations from a central site location.

Methods of Analysis

Study Area

Hamilton, Ontario, Canada, is an area with a long history of research on air pollution (Adams et al., 2012; Arain et al., 2007, 2009; Buzzelli et al., 2003; Jerrett et al., 2004, 2001; Kanaroglou et al., 2013; Sahsuvaroglu et al., 2006; Wallace and Kanaroglou, 2008; Wallace et al., 2009, 2010), with a population of about 520,000 (Statistics Canada, 2012). The city is diverse in land use with a major industrial complex along the cities' northern edge. Two intercity freeways flow through the city, one along the north end of the city and one along the western side of the city. Two intra-city freeways complete the freeway network, with one freeway in the city's southern region and another in the west. The city is separated by an escarpment, which is a significant factor in accessibility as few options exists for getting up or down it. The escarpment is also responsible for different air pollution conditions, during elevated air pollution episodes in the lower city caused by temperature inversions (Wallace et al., 2010). Overall Hamilton has significant spatial variation in socio-economic factors and air pollution concentrations.

Home to School Shortest Path Analysis

Children on their journey between home and school most often take the shortest path (Cooper *et al.* 2010; Hill, 1984). Our analysis constrained the potential paths to school catchment areas, in that no routes would be generated where a student would travel to a school outside of their catchment area. The public school board for the study area, Hamilton Wentworth District School Board, identifies that roughly 80% of children reside within the catchment area of their primary school (Hamilton Wentworth District School Board, 2011). In the region, active transportation is only likely for students living within 1.6 km of their school, beyond this distance students are provided transportation by the school board. School catchment boundaries were provided to us by the local school board (Hamilton Wentworth District School Board, 2012).

The shortest paths were derived along a pedestrian network, which includes different route options from the standard vehicular network; particularly, green-pathways that include parks, schoolyards, walking trails and other corridors. The base network included all road links in the study area (City of Hamilton, 2010), which was supplemented with green-pathway data (City of Hamilton, 2005) and manually edited using on-screen digitizing of short-cuts and unmarked pedestrian infrastructure with satellite imagery (Google Inc., 2013). Road links that prohibit walking were removed, which included expressways and major highways.

During route assignment, destinations are defined as primary school locations, which serve students between the ages of five and fourteen. Origins were defined using a parcel land database that identifies the lot of each house (City of Hamilton, 2010).Houses were randomly selected within the dissemination area until the child population was distributed to match dissemination area population statistics (Statistics Canada, 2008). At each of the randomly selected dwellings, the shortest route to school using the pedestrian road network database was determined.

Dose Exposure Analysis

Air pollution dose is dependent on the ambient concentrations and the breathing rate of the exposed person, which is often measured as the number of litres of air per minute (minute ventilation rate). Minute ventilation rates were obtained with METs rates for both cycling and walking from the EPA's Child-Specific Exposure Factors Handbook (United States Environmental Protection Agency, 2008). This required determining the metabolic equivalent (MET) for both activities. Arvidsson et al.(2007) included a review of Children's activities and the associated MET values, along with their own the determination of MET values for many activities. We use the rate of 12 km hr^{-1} for the cycling speed and 4 km $hr^{-1}$for walking speeds, which have corresponding MET rates of 5.9 and 3.3 respectively in children (Arvidsson et al., 2007).Using the MET values we translate these to MVR with the EPA's Child-Specific Exposure Factors Handbook, which presents percentile data of MVR for different ranges of METs values. To estimate the MVR rates we recreated the distribution for the moderate activity MVR rates, which ranged between 3 and 6 METs. Both cycling and walking have MET rates between 3 and 6. We obtained MVR rates by determining the percentile of the MET value within the 3 to 6 range, and then chose from the MVR distribution the corresponding value for that percentile. The MVR rates we estimated are in Table 2.

Table 2: MET and MVR rates for both modes with velocity.

Activity	METs	MVR (m^3 / minute)	Velocity (m/min)
Cycling 12 km/hr	5.9	0.035	200
Walk 4 km/hr	3.3	0.017	66

Statistical Analysis

Our analysis examined how the number of litres of air consumed changes based solely on distance travelled along different trip lengths, up to a distance of 1600 m. We then obtained the mean air pollution concentrations for each month at a central air pollution monitor in Hamilton, Ontario for the hour of 8 am (Ontario Ministry of the Environment). For each month, we calculated the air pollution dose for every trip between home and school. Using a paired t-test we determined if any significant differences occurred between the two modes for the total dose of air pollution.

3.0 Results

First, we present the two functions for calculating the amount of air consumed for each meter travelled by walking (formula 1) and cycling (formula 2). We plot the two functions between 0 and 1600 m, showing how the liters consumed changes over this distance in figure 1. Dose is determined by multiplying the litres consumed by the concentration.

$$LC = Dw \,/\, 66 \, * \, 0.017 \qquad 1$$

$$LC = Dc \,/\, 200 \, * \, 0.035 \qquad 2$$

Where LC is the liters consumed, *Dw* is the distance walked, and *Dc* is the distance cycled.

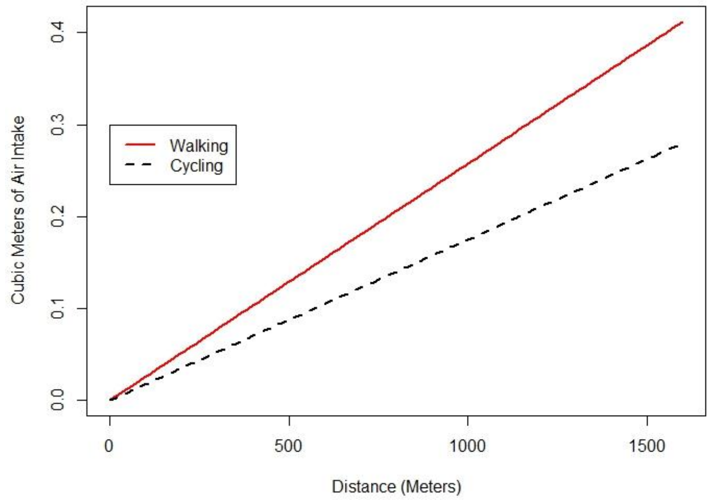

Figure 1: Air Consumed when Walking or Cycling for 0 and 1600 meters.

We present an analysis of the average and maximum dose for walking and cycling for average monthly conditions during 8 am in table 3.

Table 3: Average and maximum dose for walking and cycling for average monthly conditions during 8 am.

Month	Mean Concentration	Dose - Walk μ	Dose - Walk Max	Dose - Cycle μ	Dose - Cycle Max
Sept	7	1.33	9.3	0.91*	6.3
October	8	1.53	10.6	1.03*	7.2
March	10	1.91	13.3	1.3*	9.0
April	6	1.14	8.0	0.78*	5.4
May	12	2.29	16.0	1.55*	10.9
June	8	1.53	10.6	1.03*	7.2

*Significantly smaller dose for cycling at $p < 0.001$.

Discussion and Conclusion

Our preliminary results indicate that students should ride their bike to school when they engage in active transportation. This mode of transportation results in a statistically significantly lower air pollution dose for all cases. This reduced air pollution dose is caused by the energy efficiencies that the bike introduces by reducing the travel time.

Our future research will calculate air pollution dose using an air pollution model to include the spatial variability of the particulate matter. The central monitor is located away from any roads and likely underestimates the actual dose that would be encountered along the active transportation routes. Our findings will still be the same that cycling is a better option, but the final doses will change. We will also examine if particular housing or school locations result in students have a significantly higher dose.

References

Adams, M.D., De Luca, P.F., Corr, D., Kanaroglou, P.S., 2012. Mobile Air Monitoring: Measuring Change in Air Quality in the City of Hamilton, 2005–2010. Soc. Indic. Res. 108, 351–364.

Arain, M. A., Blair, R., Finkelstein, N., Brook, J.R., Sahsuvaroglu, T., Beckerman, B., Zhang, L., Jerrett, M., 2007. The use of wind fields in a land use regression model to predict air pollution concentrations for health exposure studies. Atmos. Environ. 41, 3453–3464.

Arain, M.A., Blair, R., Finkelstein, N., Brook, J., Jerrett, M., 2009. Meteorological influences on the spatial and temporal variability of NO 2 in Toronto and Hamilton. Can. Geogr. / Le Géographe Can. 53, 165–190.

Arvidsson, D., Slinde, F., Larsson, S., Hulthén, L., 2007. Energy cost of physical activities in children: validation of SenseWear Armband. Med. Sci. Sports Exerc. 39, 2076–84.

Baxter, L.K., Burke, J., Lunden, M., Turpin, B.J., Rich, D.Q., Thevenet-Morrison, K., Hodas, N., Ökaynak, H., 2013. Influence of human activity patterns, particle composition, and residential air exchange rates on modeled distributions of PM2.5 exposure compared with central-site monitoring data. J. Expo. Sci. Environ. Epidemiol. 23, 241–7.

Briggs, D.J., de Hoogh, K., Morris, C., Gulliver, J., 2008. Effects of travel mode on exposures to particulate air pollution. Environ. Int. 34, 12–22.
Brunekreef, B., Janssen, N., Hartog, J. de, Harssema, H., Knape, M., van Vliet, P., 1997. Air pollution from truck traffic and lung function in children living near motorways. Epidemiology 8, 298–303.
Buonanno, G., Stabile, L., Morawska, L., 2013. Personal exposure to ultrafine particles: The influence of time-activity patterns. Sci. Total Environ. 468-469C, 903–907.
Buzzelli, M., Jerrett, M., Burnett, R., Finklestein, N., 2003. Spatiotemporal perspectives on air pollution and environmental justice in Hamilton, Canada, 1985–1996. Ann. Assoc. Am. Geogr. 93, 557–573.
Christoph Bergmeir, Jose M. Benitez (2012). Neural Networks in R Using the Stuttgart Neural Network Simulator: RSNNS. Journal of StatisticalSoftware, 46(7), 1-26. URL http://www.jstatsoft.org/v46/i07/.
City of Hamilton. (2005).*Bikeways, Trails and Parks of the City of Hamilton.* City of Hamilton Public Works Department: Hamilton, Ontario.
City of Hamilton. (2010). *City of Hamilton Vector GIS Dataset*. City of Hamilton GIS Services: Hamilton, Ontario.
Cooper, A.R., Page, A.S., Wheeler, B.W., Griew, P., Davis, L., Hillsdon, M., &Jago, R. (2010). Mapping the walk to school using accelerometry combined with a global positioning system. *American Journal of Preventative Medicine,* 38(2), 178-183.
Dons, E., Van Poppel, M., IntPanis, L., De Prins, S., Berghmans, P., Koppen, G., Matheeussen, C., 2014. Land use regression models as a tool for short, medium and long term exposure to traffic related air pollution. Sci. Total Environ. 476-477C, 378–386.
Freire, C., Ramos, R., Puertas, R., Lopez-Espinosa, M.-J., Julvez, J., Aguilera, I., Cruz, F., Fernandez, M.-F., Sunyer, J., Olea, N., 2010. Association of traffic-related air pollution with cognitive development in children. J. Epidemiol. Community Health 64, 223–8.
Gauderman, W., Avol, E., Gilliland, F.D., Vora, H., Thomas, D., Berhane, K., McConnell, R., Kuenzil, N., Lurmann, F., Rappaport, E., Margolis, H., Bates, D., Peters, J., 2004. The effect of air pollution on

lung development from 10 to 18 years of age. New EnglandeJounal Med. 351, 1057–1067.
Gauderman, W.J., 2000. Association between air pollution and lung function growth in southern California children. Am. J. … 162, 1383–90.
Google Inc. (2013). *Google Earth, Version 7.1.2.2041*. Google Inc: Mountain View, CA.
Gulliver, J., Briggs, D.J., 2004. Personal exposure to particulate air pollution in transport microenvironments. Atmos. Environ. 38, 1–8.
Hamilton Wentworth District School Board. (2011). *In-catchment and out-of-catchment students-elementary schools*. Accommodation and Planning: Hamilton, Ontario.
Hamilton Wentworth District School Board. (2012). *Elementary School Catchment Area Boundaries and Elementary School walking Distance Boundaries*. Accommodation and Planning: Hamilton, Ontario.
Heck, J.E., Park, A.S., Qiu, J., Cockburn, M., Ritz, B., 2013. An exploratory study of ambient air toxics exposure in pregnancy and the risk of neuroblastoma in offspring. Environ. Res. 1–6.
Hill, M. (1984). Walking straight home from school: Pedestrian route choice by young children. *Transportation Research Board*, 955, 51-55.
Hutter, H.-P., Haluza, D., Piegler, K., Hohenblum, P., Fröhlich, M., Scharf, S., Uhl, M., Damberger, B., Tappler, P., Kundi, M., Wallner, P., Moshammer, H., 2013. Semivolatile compounds in schools and their influence on cognitive performance of children. Int. J. Occup. Med. Environ. Health 26.
IntPanis, L., de Geus, B., Vandenbulcke, G., Willems, H., Degraeuwe, B., Bleux, N., Mishra, V., Thomas, I., Meeusen, R., 2010. Exposure to particulate matter in traffic: A comparison of cyclists and car passengers. Atmos. Environ. 44, 2263–2270.
Jerrett, M., Arain, M.A., Kanaroglou, P., Beckerman, B., Crouse, D., Gilbert, N.L., Brook, J.R., Finkelstein, N., Finkelstein, M.M., 2007. Modeling the intraurban variability of ambient traffic pollution in Toronto, Canada. J. Toxicol. Environ. Health. A 70, 200–12.
Jerrett, M., Burnett, R.T., Brook, J., Kanaroglou, P., Giovis, C., Finkelstein, N., Hutchison, B., 2004. Do socioeconomic characteristics modify the short term association between air

pollution and mortality? Evidence from a zonal time series in Hamilton, Canada. J. Epidemiol. Community Health 58, 31–40.
Jerrett, M., Burnett, R.T., Kanaroglou, P., Eyles, J., Finkelstein, N., Giovis, C., Brook, J.R., 2001. A GIS - environmental justice analysis of particulate air pollution in Hamilton, Canada. Environ. Plan. A 33, 955–973.
Kanaroglou, P.S., Adams, M.D., De Luca, P.F., Corr, D., Sohel, N., 2013. Estimation of sulfur dioxide air pollution concentrations with a spatial autoregressive model. Atmos. Environ. 79, 421–427.
Metrolinx (2011) *Greater Toronto and Hamilton area school travel household attitudinal study report*. Stepping it up: Hamilton, Ontario.
Moridi, M., Ziaei, S., Kazemnejad, A., 2013. Exposure to ambient air pollutants and spontaneous abortion. J. Obstet. Gynaecol. Res. n/a–n/a.
R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URLhttp://www.R-project.org/.
Sahsuvaroglu, T., Arain, A., Kanaroglou, P., Finkelstein, N., Newbold, B., Jerrett, M., Beckerman, B., Brook, J., Finkelstein, M., Gilbert, N.L., 2006. A land use regression model for predicting ambient concentrations of nitrogen dioxide in Hamilton, Ontario, Canada. J. Air Waste Manag. Assoc. 56, 1059–69.
Statistics Canada. (2008). Profile for Canada, Provinces, Territories, Census Divisions, Census Subdivisions and Dissemination Areas, 2006 Census. Profile of Dissemination Areas. 2006 Census. Statistics Canada Catalogue no. 941-581-X2006002. Ottawa. Released May 29, 2008.
Statistics Canada. 2012. Focus on Geography Series, 2011 Census. Statistics Canada Catalogue no. 98-310-XWE2011004. Ottawa, Ontario. Analytical products, 2011 Census. Last updated October 24, 2012.
Suglia, S.F., Gryparis, A., Wright, R.O., Schwartz, J., Wright, R.J., 2008. Association of black carbon with cognition among children in a prospective birth cohort study. Am. J. Epidemiol. 167, 280–6.
United States Environmental Protection Agency, 2008. Child-Specific Exposure Factors Handbook.
Urman, R., McConnell, R., Islam, T., Avol, E.L., Lurmann, F.W., Vora, H., Linn, W.S., Rappaport, E.B., Gilliland, F.D., Gauderman,

W.J., 2013. Associations of children's lung function with ambient air pollution: joint effects of regional and near-roadway pollutants. Thorax 1–8.
Wallace, J., Corr, D., Deluca, P., Kanaroglou, P., McCarry, B., 2009. Mobile monitoring of air pollution in cities: the case of Hamilton, Ontario, Canada. J. Environ. Monit. 11, 998–1003.
Wallace, J., Corr, D., Kanaroglou, P., 2010. Topographic and spatial impacts of temperature inversions on air quality using mobile air pollution surveys. Sci. Total Environ. 408, 5086–96.
Wallace, J., Kanaroglou, P., 2008. Modeling NOx and NO2 emissions from mobile sources: A case study for Hamilton, Ontario, Canada. Transp. Res. Part D Transp. Environ. 13, 323–333.
Wallner, P., Kundi, M., Moshammer, H., Piegler, K., Hohenblum, P., Scharf, S., Fröhlich, M., Damberger, B., Tappler, P., Hutter, H.-P., 2012. Indoor air in schools and lung function of Austrian school children. J. Environ. Monit. 14, 1976–82.
Wong, E.Y., Gohlke, J., Griffith, W.C., Farrow, S., Faustman, E.M., 2003. Assessing the Health Benefits of Air Pollution Reduction for Children. Environ. Health Perspect. 112, 226–232.
Zuurbier, M., Hoek, G., van den Hazel, P., Brunekreef, B., 2009. Minute ventilation of cyclists, car and bus passengers: an experimental study. Environ. Health 8, 48.