**TITLE PAGE**


**Full title:** Bicycle commuting and exposure to air pollution: a questionnaire-based investigation of perceptions, symptoms and risk management strategies

**Running head:** Bicycle commuting and exposure to air pollution

**Manuscript type:** Original Research

**Key words:** environment; air pollution; physical activity; commute; public health; survey research


**Abstract word count:** 199

**Manuscript word count:** 4665

**Date of manuscript submission:** March 16th, 2013

**Date of manuscript re-submissions:** August 29th, 2013

**Date of second manuscript re-submission:** February 14th, 2014

Cole-Hunter, T.[1,2,3,*], Morawska, L. [1,2], Solomon, C.[3,4]

[1] Institute of Health and Biomedical Innovation, Queensland University of Technology, 60 Musk Avenue, Brisbane, QLD 4059, Australia

[2] International Laboratory for Air Quality and Health, Queensland University of Technology, 2 George Street, Brisbane, QLD 4001, Australia

[3] School of Life Sciences, Queensland University of Technology, 2 George Street, Brisbane, QLD 4001, Australia

[4] School of Health and Sport Sciences, University of the Sunshine Coast, Sippy Downs Drive, Sippy Downs, QLD 4556, Australia

* Corresponding author: tcolehunter@gmail.com

**ABSTRACT**

**Background:** An increase in bicycle commuting participation may improve public health and traffic congestion in cities. Information on air pollution exposure (such as perception, symptoms and risk management) contributes to the responsible promotion of bicycle commuting participation.

**Methods:** To determine perceptions, symptoms and willingness for specific exposure risk management strategies of exposure to air pollution, a questionnaire-based cross-sectional investigation was conducted with adult bicycle commuters (n = 153; age = 41 ± 11 yr; 28% female).

**Results:** Frequency of acute respiratory signs and symptoms are positively-associated with in- and post-commute compared to pre-commute time periods ($p < 0.05$); greater positive-association is with respiratory disorder compared to healthy, and female compared to male, participants. The perception (although not signs or symptoms) of in-commute exposure to air pollution is positive-associated with the estimated level of in-commute proximity to motorised traffic. The majority of participants indicated a willingness (which varied with health status and gender) to adopt risk management strategies (with certain practical features) if shown to be appropriate and effective.

**Conclusions:** While acute signs and symptoms of air pollution exposure are indicated with bicycle commuting, and more so in susceptible individuals, there is willingness to manage exposure risk by adopting effective strategies with desirable features.

# 1.    Introduction

Bicycle commuting requires physical exercise and is a combustion-fuel-independent transport mode. Therefore, bicycle commuting is increasingly being promoted as a partial solution for physical-inactivity-related cardiovascular disease, intra-urban motorised-traffic congestion, and anthropogenic climate change [1-4]. However, barriers (either real or perceived) to the use of bicycle commuting include the higher risk of exposure to air pollution, traffic accidents and adverse weather conditions [1,5,6]. Exposure to air pollution is a health risk which can be increased with higher pulmonary ventilation (associated with physical exercise) [7-10] and closer proximity to motorised traffic emissions [6,8,11-15]. However, the health benefits correlated with improved air quality and an increase in physical exercise could negate certain health risks [4,5,16]. Primary air pollutants (being emitted from motorised traffic) of relevance to bicycle commuting in urban environments include particulate matter (PM) and nitrogen dioxide ($NO_2$) [15]. These pollutants can be detected by humans by sight or smell and exposure to these pollutants can elicit acute respiratory symptoms [5]. Nasopharyngeal irritation, airway inflammation and bronchoconstriction [manifesting as cough and phlegm production (tussis), and chest tightness or wheezing] are rapid-onset and short-duration (acute) symptoms, of which manifestation can occur in an individual exposed to elevated PM and $NO_2$ levels, particularly for individuals having pre-disposing respiratory disorder such as asthma [17]. Chronic exposure to elevations of these pollutants can suppress airway immune defences and consequently increase the frequency and severity of upper respiratory tract infections [18,19]. Questionnaire-based reporting of acute symptoms has been used to assess exposure to air pollution in healthy children and adults, and asthmatic children and adults [20-22], as well as for specifically in women compared to men [23,24], the elderly [25] and the general community [26,27]. Additionally, questionnaires have been used successfully to investigate perceptions of exposure to multi-modal air pollution in work-related commuting [28]. Investigation of the

perception of exposure to air pollution is necessary to inform those involved in the transition from passive motorised transport modes to active bicycle commuting. The results of such an investigation can provide information on the appropriateness and efficacy of risk management strategies (such as commute re-routing or respirator use) for the general population and particularly for individuals with a pre-disposition (susceptibility) to increased effects of exposure to air pollution. The successful adoption of these strategies is dependent on the desirability of the features of the strategy (including off-road bicycle paths and air-filtering respirators) for the potential users.

The specific aims of the project were to determine, in adult urban bicycle commuters: (1) the frequency and correlation of acute respiratory symptoms with estimated proximity to motorised traffic, and pre-disposing factors of age, gender and respiratory disorder; (2) if individual perception of in-commute exposure to air pollution is associated with estimated proximity to motorised traffic (however not to compare perceived or estimated exposure to measured or actual exposure); and, (3) the willingness of individuals to adopt risk management strategies for exposure to air pollution and the desirability of specific features of the strategy . Accordingly, it was hypothesised that in adult bicycle commuters: (1) the frequency of acute respiratory symptoms will be positively-associated with estimated proximity to motorised traffic, and respiratory disorder, and female gender; (2) the perceived exposure levels of air pollution will be positively-associated with estimated proximity to motorised traffic ; and, (3) the willingness of participants to adopt air pollution exposure risk management strategies will be positively-associated with perceived exposure levels and frequency of, or pre-disposition to, acute respiratory symptoms.


2.     Methods

## 2.1. Project design

This project was a questionnaire-based investigation using a cross-sectional design. Participants were adults and frequent bicycle commuters having a commute which included the Central Business District of Brisbane city (Australia). The questionnaire measured variables that were descriptive (of the participant and the commute), independent (as the participant or commute condition) and dependent (such as the participant response regarding perceptions and symptoms of air pollution exposure and the desirability of features for risk management strategies). Measurements were taken (via questionnaire administration) during the three month period from March to June of 2010; however, the questionnaire was designed to measure (via recollection) a participant's typical bicycle commute experience for the total period for which they had used their current commute route.

## 2.2. Questionnaire design

The questionnaire used in this investigation was purpose-designed and incorporated review and input from researchers and a sub-set of intended participants. The format of the assessment of acute respiratory signs and symptoms attributable to exposure to air pollution was based on recommendations by the American Thoracic Society [29] and previous research [30]. The total of 77 questions included questions which used a common 5-point scale (43 questions: 1 = very low; 2 = low; 3 = moderate; 4 = high; 5 = very high), or were of categorical (5 questions), continuous (12 questions) or nominal (17 questions) format. The complete questionnaire is available in a supplemental file.

### 2.2.1. Acute respiratory signs and symptoms

The frequency of acute respiratory signs and symptoms [including detection of offensive odour, nasopharyngeal irritation, tussis, chest tightness and wheezing] were collected using

the common 5-point scale specifically for the time periods of one hour before bicycle commuting (pre-commute), during bicycle commuting (in-commute), and one hour after bicycle commuting (post-commute). The one-hour period pre-commute and post-commute was used to isolate in-commute exposure from other daily environmental exposures. To decrease the effect of individual subjectivity, an acute respiratory symptom was only used when the frequency was moderate / 3 or greater. The detection of offensive odour is considered an acute respiratory sign [29] and could be used for self-management of exposure to air pollution when the presence of air pollution is not well perceived.

### 2.2.2. Perception of exposure to air pollution

Perception of in-commute exposure to air pollution (perceived by sight or smell) was reported by participants for presence (yes/no) and level (using the common 5-point scale). To address individual response subjectivity, as with the sign and symptom reporting, a participant was considered to perceive exposure to air pollution only when they reported the presence as moderate / 3 or greater.

### 2.2.3. Exposure risk management strategies

Participants reported willingness to change their commute route or wear a respirator if it was shown that these strategies were appropriate and effective at reducing risk for exposure to air pollution while bicycle commuting (see exact wording in the questionnaire provided as a supplemental file). Additionally, participants rated the importance (desirability) of specific features of the strategies. The intention of this component was to indicate which strategy and features could warrant future research as well as infrastructure/product and policy development. Brisbane bikeway maps [31] were appended to the end of the questionnaire for a participant's reference when determining their commute route's off-road proportion and their willingness to commute re-routing.

2.3.    Participant recruitment and group

Potential participants were recruited through the university and major Brisbane bicycle user groups, and  newspaper and radio segments. Eligible participants were adults and frequent bicycle commuters of the Brisbane inner-city region (i.e., those completing $\geq$ two return trips in a five week-day period to a destination within a one kilometre radius of the Brisbane Central Business District).  The rationale for the participant inclusion criterion of $\geq$ two return trips is based on the expectation that this frequency would allow sufficient experience of the participant for the specific content of this investigation. Potential participants who were current smokers or who had ceased smoking less than 24 months at the time of the project were not eligible to  participate; however, participants that had ceased smoking greater than 24 months prior to the time of the project were eligible to participate.

The questionnaire was distributed to eligible participants as a paper copy with a reply paid envelope or an electronic copy via return E-mail. Participants were instructed to respond in reference to their typical bicycle commuting experience for the total period for which they had used their current commute route. The project was  approved by the Human Research Ethics Committee of the Queensland University of Technology. Participants indicated informed consent by returning the completed questionnaire. The estimated target population size, according to bicycle user group membership of targeted organisations during recruitment, was 500. Of these, approximately 200 potentially-eligible individuals expressed interest to participate. 160 were confirmed as eligible and were supplied with the questionnaire.  60 of 61 electronic versions and 93 of 99 paper versions were returned for an overall response rate of 96%. A total of 153 questionnaires were completed (with 43 by females). Participant characteristics including frequency of return bicycle commutes per week indicate that the participants were frequent bicycle commuters with a variety of commuting experience (Table 1).

INSERT TABLE 1 HERE

## 2.4.    Data analyses

The response data (for frequency of symptoms and perception, and  willingness for risk

minimisation strategy) of the common 5-point scale were collated to provide group mean

values for statistical analyses. Sub-groups of participant gender,  and previous respiratory

disorder (as a previous diagnosis of airway or lung condition / disease / disorder) or smoking

history (as a previous history of habitual smoking of tobacco or any other substance),  were

used to compare frequency of symptoms between the pre-commute, in-commute and post-

commute time periods.

To provide a general estimation of the time spent proximal to motorised traffic (here-after

referred to as PROX) in-commute, a ranking was calculated for individual participants as the

product of their trip duration, frequency and use of motorised traffic corridors (being the

proportion of route on-road, or route shared with motorised traffic) for their current typical

bicycle commute. The reported on-road proportion of a typical bicycle commute was

categorised into deciles [1-10% (0.1), 11-20% (0.2), 21-30% (0.3), 31-40% (0.4), 41-50%

(0.5), 51-60% (0.6), 61-70% (0.7), 71-80% (0.8), 81-90% (0.9), and 91-100% (1.0)]. This

decile was then multiplied by the trip duration (minutes) and the frequency (number of return

trips per week) for a proportion of the total time spent proximal to motorised traffic whilst

bicycle commuting on a weekly basis. The product of this process allocated participants a

quintile rank of either 1 (very low; n = 30), 2 (low; n = 32), 3 (moderate; n = 30), 4 (high; n =

32) or 5 (very high; n = 32) to represent the level of estimated average proximity to motorised

traffic and the associated exposure to air pollution emissions.

The questionnaire responses were analysed using predictive analytics software (PASW

Statistics Data Editor, V18.0; IBM Corporation, USA). The data were first tested to be

normally-distributed. Descriptive analysis used means and standard deviations. One-way analyses of variance (ANOVA) were performed to identify differences between total group mean responses (of perception and symptom frequency) at pre-commute, in-commute and post-commute time periods. Subsequently, Tukey HSD Post Hoc comparisons were performed with these ANOVA to identify specific pair-wise differences. Further, sub-group stratification analysis was conducted by gender and by health status (as healthy versus either respiratory disease or smoking history). Finally, Fisher's Exact Test and Pearson's Chi Square Test were performed to assess the effect of participant and commute characteristics (of PROX, of either respiratory disorder or smoking history, and gender) on participant responses, and the association of intra-individual participant responses. Statistical significance was indicated at the 95% confidence level (i.e. $p < 0.05$), which was not adjusted for repeated measures. Not all questionnaire items of this project are reported here so as to refine the scope of this article – these items, of which the outcomes were generally insignificant, may be considered for a future article.

## 3.     Results

### 3.1.     Reporting of signs and symptoms of exposure to air pollution

#### 3.1.1. Healthy participants

Healthy participants generally reported a significantly higher frequency of specific acute respiratory symptoms in- and post-commute compared to pre-commute ($p < 0.05$; Table 2). In-commute detection of offensive odour was positively-associated with in-commute nasopharyngeal irritation [$F_{(29,99)} = 11.22$, $p < 0.001$], tussis [$F_{(18,151)} = 4.50$, $p = 0.002$], chest tightness [$F_{(10,87)} = 4.39$, $p = 0.002$] and wheezing [$F_{(6,79)} = 2.82$, $p = 0.027$].

Further, in-commute detection of offensive odour was positively-associated with post-commute nasopharyngeal irritation [$F(13,178) = 2.84$, $p = 0.026$], tussis [$F(8,107) = 2.97$, $p = 0.022$] and chest tightness [$F(3,51) = 2.50$, $p = 0.045$] of healthy individuals.

INSERT TABLE 2 HERE

The total group mean estimated time spent in-commute proximal to motorised traffic (PROX) was $52 \pm 2.8$ % (Table 3). PROX was positively-associated with the frequency of in-commute detection of offensive odour [$F(18,160) = 2.08$, $p = 0.041$]. PROX, however, was not correlated with the frequency of any acute respiratory symptoms, either in-commute ($p \geq 0.113$) or post-commute ($p \geq 0.095$).

Females reported a significantly higher frequency of in-commute nasopharyngeal irritation ($p = 0.009$) and chest wheeze ($p = 0.046$), and post-commute nasopharyngeal irritation ($p = 0.006$) compared to males (Table 2, Table 3). Sub-groups of gender showed no significant differences of PROX (Table 3).

INSERT TABLE 3 HERE

*3.1.2. Health-compromised participants*

For participants with smoking history, the frequency of in-commute detection of offensive odour was significantly lower compared to healthy participants ($p < 0.05$; Table 4). For participants with respiratory disorder, the frequency of acute respiratory symptoms (nasopharyngeal irritation, tussis, chest tightness and wheezing) was significantly higher compared to healthy participants ($p < 0.05$; Table 4). Sub-groups of smoking history or respiratory disorder showed no significant differences of PROX (Table 5).

INSERT TABLE 4 HERE

INSERT TABLE 5 HERE

3.2.    Reporting of perception of exposure to air pollution

*3.2.1. Healthy participants*

The majority of healthy participants reported perception (through sight or smell) of in-commute exposure to air pollution at moderate or higher levels (Table 3). The frequency of this exposure perception reporting was positively-associated with in-commute detection of offensive odour [$F(43,136) = 48.25$, $p < 0.001$], nasopharyngeal irritation [$F(8,120) = 10.63$, $p = 0.001$] and chest wheeze [$F(2,82) = 4.59$, $p = 0.034$]. Additionally, this exposure perception was positively-associated with the number of weekly return trips performed [$F(9,256) = 5.50$, $p = 0.020$].

PROX was positively-associated with the level of in-commute perception of exposure to air pollution [$F(3,22) = 2.31$, $p = 0.023$].

Females reported a significantly higher level of in-commute perception of exposure to air pollution ($p = 0.039$) compared to males (Table 3).

*3.2.2. Health-compromised participants*

For participants with smoking history, the level of in-commute perception of exposure to air pollution was significantly lower compared to healthy participants ($p < 0.05$; Table 5).

3.3.    Risk management strategies for exposure to air pollution

*3.3.1.  Commute re-route*

The majority of participants indicated willingness for commute re-routing as an exposure risk management strategy if proven to be appropriate and effective. Sub-groups of  gender and health status showed different levels of willingness within their own group (Table 3, Table 5).

Particularly, females were significantly more willing to commute re-route compared to males ($p < 0.05$; Table 3).

The desirability of the features of the commute re-routing strategy were, as a group mean from highest to lowest, safety ($4.0 \pm 0.5$), time ($3.8 \pm 0.3$), fitness ($2.9 \pm 1.2$), health ($2.9 \pm 0.4$) and social ($1.5 \pm 0.7$) features. PROX was negatively-associated with participant-rated desirability of health [$F(34,196) = 3.25$, $p = 0.002$] and safety [$F(31,182) = 3.10$, $p = 0.003$] features.

### 3.3.2. Respirator use

Zero participants reported currently using a respirator during their bicycle commute. However, approximately one fifth (21%) of participants had previously considered such use, and this previous consideration was positively-associated with in-commute detection of offensive odour [$F(3,22) = 4.52$, $p = 0.002$] and perception of exposure to air pollution [$F(1,23) = 6.33$, $p = 0.013$].

The majority of participants indicated willingness to use a respirator as an exposure risk management strategy if proven to be appropriate and effective. Similar to commute re-routing (although insignificantly) for respirator use, sub-groups of gender and health status showed different levels of willingness within their own group (Table 3, Table 5).

The desirability of the features of the respirator use strategy were, as a group mean from highest to lowest, breathing impedance ($3.9 \pm 0.4$), wear comfort ($3.7 \pm 0.6$), appearance ($2.9 \pm 1.5$) and expense ($2.5 \pm 0.8$).

## 4.    Discussion

4.1. Summary of project results

The hypotheses of the current project of adult bicycle commuters followed two main themes. Firstly, the frequency of acute respiratory symptoms and perceived levels of exposure to air pollution will be positively-associated with estimated proximity to motorised traffic, and more positively-associated with (susceptibility by) respiratory disorder or female gender. Secondly, the willingness to adopt air pollution exposure risk management strategies will be positively-associated with perceived levels of, and susceptibility to, exposure to air pollution. The major results of this project suggest that in healthy individuals, the frequency of specific acute respiratory symptoms is higher in-commute and post-commute compared to pre-commute. The frequency of acute respiratory symptoms associated with bicycle commuting is higher in respiratory disorder compared to healthy, and female compared to male, sub-groups of participants. A significant positive-association exists between the perceived level of in-commute exposure to air pollution and the estimated level of in-commute proximity to motorised traffic in healthy participants. However, PROX was not associated with the reported frequency of acute respiratory symptoms in or post commute in healthy participants. The majority of participants indicated that they were willing to adopt the risk management strategies of commute re-routing and respirator use if these strategies were shown to be appropriate and effective by future research, and that they would desire certain practical features.

4.2. Perception, signs and symptoms of exposure to air pollution

The detection of offensive odours, associated with vapour gases such as nitrogen dioxide ($NO_2$), has previously been positively-associated with the frequency of acute respiratory symptom reporting [32]. Populations living near air pollution sources (perceived by smell as odours) have reported consistent patterns of subjective symptoms, including exacerbation of

underlying medical conditions and stress-induced illness from exposure to offensive odour [26,33,34]. This perception of odour and irritation may occur at levels below the regulation limits for constituents of air pollution [35]; however, individuals have been shown to be capable of both under-estimation and over-estimation of exposure (when comparing self-reported perception and symptoms to direct air quality measurements) [36,37]. The increased frequency of acute respiratory symptoms in participants with susceptibility has also been observed in past research [20,23] including questionnaire-based studies [20,22-27,38,39]. Participants in the current project with a respiratory disorder were more susceptible to exposure-related acute respiratory symptoms. Additionally, a respiratory disorder increased, and a smoking history decreased, the perception of in-commute air pollution presence (compared to healthy participants). This finding is in agreement with previous observations [40]. Further, females have previously indicated a higher frequency of symptoms than males for gas cooking [23] and cigarette smoking exposure [24] consisting of both vapour gas and particulate matter pollution. Therefore, communication of accurate air pollution levels and education of consequential exposure risk would be beneficial when self-managing exposure risk strategies, particularly in unfavourable meteorological conditions and susceptible individuals.

Exposure to $NO_2$ can induce inflammation in the lower airways and exacerbate asthma and chronic bronchitis [19,41]. During the period of the current project, in Brisbane the ambient $NO_2$ annual mean was 7 parts per billion (ppb), with a daily peak 1-hour mean of 37 ppb [45]. At such levels, acute respiratory symptoms in healthy adults have not been shown. However, as $NO_2$ is a major component of emissions from motorised traffic, exposure concentrations are expected to be much higher when adjacent to major traffic corridors. Brisbane's roadside mean $NO_2$ concentrations have been recorded at between 18 and 34 ppb with peaks of approximately 60 ppb positively-correlated with morning (7:00 to 8:00 AM) and afternoon (4:00 to 6:00 PM) commute traffic flow rates, indicating traffic emissions as a dominant

emission source [42]. Adults with asthma are twice as sensitive as adults without asthma to

short-term exposures of $NO_2$, however significantly increased airway resistance (due to

inflammation) has not been observed below 500 ppb [18]. Acute exposure of very high

concentrations (~5,000 to 10,000 ppb) elicit symptoms due to inflammation such as

nasopharyngeal irritation, dyspnoea and tussis in healthy adults [18]. Acute symptom frequency

(such as nasopharyngeal irritation, dyspnoea and tussis) and PROX were not significantly-

correlated in the current project, possibly explained by the relatively-low roadside traffic-

associated emissions (including $NO_2$ and PM) compared to previously investigated regions

[18,43,44].

During the period of the current project, in south-east Queensland (SE QLD; surrounding

Brisbane, Australia) ambient $PM_{10}$ and $PM_{2.5}$ (particulate matter with diameters of 10 and 2.5

micrometres, respectively) maximum daily mean particle mass concentrations were 37 and 19

$\mu g/m^3$, respectively [45]. Previous recordings of roadside $PM_{10}$ indicated one-hour mean

concentrations of $25 \pm 13$ $\mu g/m^3$ and a maximum of 90 $\mu g/m^3$, associated with high traffic

counts and large proportions of heavy duty vehicles [42]. $PM_{2.5}$ one-hour mean concentrations

of $21 \pm 11$ $\mu g/m^3$ and a maximum of 195 $\mu g/m^3$ were also shown, with the highest values on

week-days (Monday to Friday) believed to be due to greater traffic counts and proportion of

heavy duty vehicles [42]. Exposure to particulate matter (PM) can induce inflammation in the

airways and exacerbate respiratory disorders [19,41]. However, short-term exposure to $PM_{10}$ and

$PM_{2.5}$ at regionalised outdoor mass concentrations of $14 \pm 7$ and $11 \pm 5$ $\mu g/m^3$, respectively,

has not been associated with detrimental health effects in young, healthy participants

performing exercise [46]. As roadside PM concentrations in this project were higher than that

previously shown to be non-detrimental, in-commute PM exposure could be the cause of

acute respiratory symptoms in susceptible individuals in this project; however, the greatest

concern regarding PM is considered to be the particle number concentration (that is, particle

count) rather than particle mass concentration [47]. For a specific mass concentration, ultra-fine particles (UFPs; < 0.1 μm diameter) are the main diameter range of motorised traffic particulate emissions [48]. As UFP is not routinely monitored in SE QLD, it is difficult to consider the effects on bicycle commuters directly. Therefore, future research involving direct investigation of bike-path and roadside air quality is warranted to advise the appropriateness and efficacy of implementing risk management strategies such as commute re-routing.

4.3. Risk management of exposure to air pollution

Commuters using different travel modes in SE QLD have previously indicated that they thought of exposure to air pollution as a substantial health concern although not a major barrier to participating in active transport (such as bicycle commuting) [28]. However, a limitation highlighted by the authors of this previous project was the relatively small sub-set of active commuters ($n = 64$ of 745 / 9%) surveyed. The current project (with a cohort of twice this number) extends to suggest that healthy bicycle commuters can perceive in-commute exposure to air pollution and are generally willing to reduce their exposure by adopting risk management strategies, if known to be appropriate and effective. Most participants reported to not use off-road paths for the majority of their commute route and nil used a respirator – perhaps as some commute routes do not have a high proportion of off-road bicycle paths available for use, or that there is limited knowledge of respirators available for bicycle commuters. Nevertheless, the desirability of features of a commute route or respirator were evaluated by participants. This was done to highlight those features which would most effectively support the strategy adoption by willing participants. When choosing a commute route, participants of this project indicated that the feature of time (defined as more convenient / quickest route) was more desirable than the feature of health (defined as to avoid air pollution). Therefore, convenience and quickness of use should be considered important

by developers when constructing new bicycle paths. For respirator use, participants in this project indicated that the most important features to be addressed by developers were breathing impedance and wear comfort. There are commercially-available respirators that are recommended for use by urban bicycle commuters due to their design accommodating increased ventilation rate, heat production and perspiration associated with moderate physical activity; however, as stated previously, insufficient knowledge of respirator availability may be a barrier to its use.

4.4. Limitations, strengths and implications of project

Limitations of the current project include the design of a unique questionnaire - to the authors knowledge, a precedent model was not available for reference - however, this design process was rigorously performed with the review and input of respiratory scientists, epidemiological statisticians and a sample of the intended participant cohort. Participation bias was possible due to the nature of the questionnaire (bringing focus to a subject which may discourage the act of bicycle commuting by highlighting associated dangers), however during recruitment potential participants generally expressed a positive attitude towards the issue. Response bias for risk management of exposure to air pollution, due to the questionnaire's acknowledgement of risk, may limit the ability to address the third hypothesis of this project due to the participant's inherent and expected desire to manage such risk. As only bicycle commuters were recruited, the results of this project are not transferable to the general population. As the symptoms were self-reported, misunderstandings could have arisen by question misinterpretation; however, again, due to the review process of questionnaire design, this was believed to be minimised. Further, the specifics of human exposure and the associated biological responses (reported as symptoms) to ambient air pollution are difficult to assess due to atmospheric mixing effects, time-activity patterns and meteorological influence [49], which were beyond the scope of this project. Finally, the fact that a large number

of statistical comparisons were made using data from a relatively-small cohort of participants could increase the risk of detecting false statistically-significant results.

The merit of responsibly encouraging increased participation of bicycle commuting is indicated by the fact that the mean one-way commute duration of participants was approximately 30 minutes, which coincides with daily physical-activity recommendations to reduce the risk of cardiopulmonary disease[50-52]. A strength of this project is that participants frequently performed this commute, typically twice a day on four days a week. Eligibility for participation only required two or more return trips per week (to satisfy the project's pre-determined definition of a frequent bicycle commuter) but the group mean was four trips per week, suggesting that this project represented a dedicated and experienced population of bicycle commuters. Seasonal variation of bicycle commuting participation was not investigated; however, this project took place mostly in the milder conditions of Spring (March to June) when environmental conditions are conducive to bicycle commuting due to cooler and dryer conditions.

In Australia, 50% of households possess at least one working bicycle, however only 1.5% of the population use a bicycle as their main form of transport to their place of study or work [53]. Therefore, there is potential to increase bicycle commute trips by providing information and appropriate infrastructure. This implies that future work should include investigation of the motivational determinants, both perceived and real (such as availability of off-road commute routes or respirators), for participation in bicycle commuting. This investigation may use a questionnaire which relates reported (perceived) factors to mapped (real) commute environment factors (such as off-road paths or modelled air pollution levels) within a participant's commute environment. Due to the current lack of evidence concerning the perception of exposure to air pollution, more research is required to associate perceived with real exposure. This would assist with management of health risks, such as the appropriateness

of adopting strategies for risk management including commute re-routing. Information services (such as online route-planning tools for bicycle commuters [54]) can be used to mitigate risk from exposure to air pollution, for which further investigation is recommended.

## 5. Conclusions

Exposure to air pollution while bicycle commuting is indicated to increase the frequency of self-reported acute respiratory signs and symptoms even in healthy individuals. Respiratory disorder and female gender have indicated a higher frequency for this reporting. The management of exposure risk through strategies with user-desired features (such as by the detection of offensive odours and then the adoption of convenient, off-road commute routes) could assist in the transition from passive (motorised) to active (bicycle) commuting and an increased quality of life, particularly for susceptible populations. This transition could support the contemporary increase in popularity of advocating bicycle commuting to improve environmental and public health.

**Abbreviations**: PROX (indicative estimation ranking of in-commute proximity to motorised traffic); PM (particulate matter); $NO_2$ (nitrogen dioxide); UFP (ultrafine particles); ppb (parts per billion); SE QLD (South East Queensland).

## References

**1.**    de Nazelle A, Nieuwenhuijsen M. Integrated health impact assessment of cycling. *Occup. Environ. Med.* 2010;67(2):76.

2.  de Nazelle A, Nieuwenhuijsen MJ, Antó JM, Brauer M, Briggs D, Braun-Fahrlander C, Cavill N, Cooper AR, Desqueyroux H, Fruin S, Hoek G, Panis LI, Janssen N, Jerrett M, Joffe M, Andersen ZJ, van Kempen E, Kingham S, Kubesch N, Leyden KM, Marshall JD, Matamala J, Mellios G, Mendez M, Nassif H, Ogilvie D, Peiró R, Pérez K, Rabl A, Ragettli M, Rodríguez D, Rojas D, Ruiz P, Sallis JF, Terwoert J, Toussaint JF, Tuomisto J, Zuurbier M, Lebret E. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. *Environment International.* 2011;37(4):766.

3.  Woodcock J, Edwards P, Tonne C, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet.* 2009;374(9705):1930-1943.

4.  Rabl A, de Nazelle A. Benefits of shift from car to active transport. *Transport Policy.* 2012;19(1):121-131.

5.  de Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? *Environ. Health Perspect.* 2010;118(8):1109.

6.  Weichenthal S, Kulka R, Dubeau A, Martin C, Wang D, Dales R. Traffic-related air pollution and acute changes in heart rate variability and respiratory function in urban cyclists. *Environ. Health Perspect.* 2011;119(10):1373–1378.

7.  Int Panis L, de Geus B, Vandenbulcke G, et al. Exposure to particulate matter in traffic: A comparison of cyclists and car passengers. *Atmos. Environ.* 2010;44(19):2263-2270.

8.      McNabola A, Broderick BM, Gill LW. Relative exposure to fine particulate matter and VOCs between transport microenvironments in Dublin: Personal exposure and uptake. *Atmos. Environ.* 2008;42(26):6496-6512.

9.      Zuurbier M, Hoek G, Oldenwening M, et al. Commuters exposure to particulate matter air pollution is affected by mode of transport, fuel type, and route. *Environ. Health Perspect.* 2010;118(6):783.

10.     Zuurbier M, Hoek G, Oldenwening M, Meliefste K, Van den Hazel P, Brunekreef B. Acute health effects of commuters' exposure to air pollution. *Epidemiology.* 2009;20(6):S197.

11.     Adams HS, Nieuwenhuijsen MJ, Colvile RN. Determinants of fine particle (PM2. 5) personal exposure levels in transport microenvironments, London, UK. *Atmos. Environ.* 2001;35(27):4557-4566.

12.     Briggs DJ, de Hoogh K, Morris C, Gulliver J. Effects of travel mode on exposures to particulate air pollution. *Environment International.* 2008;34(1):12-22.

13.     Kaur S, Nieuwenhuijsen MJ, Colvile RN. Pedestrian exposure to air pollution along a major road in Central London, UK. *Atmos. Environ.* 2005;39(38):7307-7320.

14.     Kaur S, Nieuwenhuijsen MJ, Colvile RN. Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. *Atmos. Environ.* 2007;41(23):4781-4810.

15.     Zhou Y, Levy J. Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC Public Health.* 2007;7(1):89.

16.     Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ: British Medical Journal.* 2011;343.

17.     Künzli N, Jerrett M, Garcia-Esteban R, et al. Ambient air pollution and the progression of atherosclerosis in adults. *PLoS One.* 2010;5(2):e9096.

18.     Lee K, Yanagisawa Y, Spengler JD, Nakai S. Carbon monoxide and nitrogen dioxide exposures in indoor ice skating rinks. *J. Sports Sci.* 1994;12:279-279.

19.     Ghio AJ, Devlin RB. Inflammatory lung injury after bronchial instillation of air pollution particles. *Am. J. Respir. Crit. Care Med.* 2001;164(4):704.

20.     Belanger K, Gent JF, Triche EW, Bracken MB, Leaderer BP. Association of indoor nitrogen dioxide exposure with respiratory symptoms in children with asthma. *American journal of respiratory and critical care medicine.* 2006;173(3):297.

21.     Johns DO, Svendsgaard D, Linn WS. Analysis of the concentration-respiratory response among asthmatics following controlled short-term exposures to sulfur dioxide. *Inhal. Toxicol.* 2010;22(14):1184-1193.

22.     Wilhelm M, Qian L, Ritz B. Outdoor air pollution, family and neighborhood environment, and asthma in LA FANS children. *Health & Place.* 2009;15(1):25-36.

23.     Jarvis D, Chinn S, Luczynska C, Burney P. Association of respiratory symptoms and lung function in young adults with use of domestic gas appliances. *The Lancet.* 1996;347(8999):426-431.

24.     Kjærgaard T, Cvancarova M, Steinsvåg SK. Cigarette smoking and self-assessed upper airway health. *Eur. Arch. Otorhinolaryngol.* 2011;268(2):219-226.

25.     van der Zee SC, Hoek G, Boezen MH, Schouten JP, van Wijnen JH, Brunekreef B. Acute effects of air pollution on respiratory health of 50-70 yr old adults. *Eur. Respir. J.* 2000;15(4):700.

26.     Aatamila M, Verkasalo PK, Korhonen MJ, et al. Odour annoyance and physical symptoms among residents living near waste treatment centres. *Environ. Res.* 2010;111(1):164-170.

27.     Stenlund T, Liden E, Andersson K, Garvill J, Nordin S. Annoyance and health symptoms and their influencing factors: a population-based air pollution intervention study. *Public Health.* 2009;123(4):339-345.

28.     Badland HM, Duncan MJ. Perceptions of air pollution during the work-related commute by adults in Queensland, Australia. *Atmos. Environ.* 2009;43(36):5791-5795.

29.     ATS. What constitutes an adverse health effect of air pollution? *Am. J. Respir. Crit. Care Med.* 2000;161:665-673.

30.     Rudell B, Ledin M, Hammarström U, Stjernberg N, Lundbäck B, Sandström T. Effects on symptoms and lung function in humans experimentally exposed to diesel exhaust. *Occup. Environ. Med.* 1996;53(10):658.

31.     BBC. Bikeway and shared pathway maps. 2010; http://www.brisbane.qld.gov.au/traffic-transport/cycling/bikeway-and-shared-pathway-maps/index.htm. Accessed 30 March, 2010.

32. Cone JE, Shusterman D. Health effects of indoor odorants. *Environ Health Persp.* 1991;95:53.

33. Lercher P, Schmitzberger R, Kofler W. Perceived traffic air pollution, associated behavior and health in an alpine area. *Sci. Total Environ.* 1995;169(1-3):71-74.

34. Shusterman D. Community health and odor pollution regulation. *Am. J. Public Health.* 1992;82(11):1566.

35. Paustenbach DJ, Gaffney SH. The role of odor and irritation, as well as risk perception, in the setting of occupational exposure limits. *Int. Arch. Occup. Environ. Health.* 2006;79(4):339-342.

36. Dalton P. Cognitive influences on health symptoms from acute chemical exposure. *Health Psychol.* 1999;18:579-590.

37. Righi E, Aggazzotti G, Fantuzzi G, Ciccarese V, Predieri G. Air quality and well-being perception in subjects attending university libraries in Modena (Italy). *Sci. Total Environ.* 2002;286(1-3):41-50.

38. Hirsch T, Weiland SK, Von Mutius E, et al. Inner city air pollution and respiratory health and atopy in children. *Eur. Respir. J.* 1999;14(3):669-677.

39. Simoni M, Annesi-Maesano I, Sigsgaard T, et al. School air quality related to dry cough, rhinitis and nasal patency in children. *Eur. Respir. J.* 2010;35(4):742.

40. Nikolopoulou M, Kleissl J, Linden P, Lykoudis S. Pedestrians perception of environmental stimuli through field surveys: Focus on particulate pollution. *The Science of the total environment.* 2011;409(13):2493-2502.

41.    Nel AE, Diaz-Sanchez D, Ng D, Hiura T, Saxon A. Enhancement of allergic inflammation by the interaction between diesel exhaust particles and the immune system. *J. Allergy Clin. Immunol.* 1998;102(4):539-554.

42.    Ayoko G, Jamriska M, Jayaratne R, Morawska L. Air pollution levels measured at traffic hot spots: Brisbane urban corridor study 2005. In Wise, Convention (Ed.) *Proceedings of 17th International Clean Air and Environment Conference*, CASANZ (Clean Air Society of Australia & New Zealand), Hobart, Tasmania, pp. 1-7.

43.    Belanger E, Kielb C, Lin S. Asthma hospitalization rates among children, and school building conditions, by New York state school districts, 1991-2001. *J. Sch. Health.* 2006;76(8):408-413.

44.    Pribyl CR, Racca J. Toxic gas exposures in ice arenas. *Clin. J. Sport Med.* 1996;6(4):232.

45.    DERM. Queensland 2010 Air Monitoring Report. 2011; http://www.derm.qld.gov.au/air/pdf/reports/2010-air-monitoring-report.pdf. Accessed 16 June, 2011.

46.    Bräuner EV, Møller P, Barregard L, et al. Exposure to ambient concentrations of particulate air pollution does not influence vascular function or inflammatory pathways in young healthy individuals. *Particle and Fibre Toxicology.* 2008;5(1):13.

47.    Oberdörster G, Oberdörster E, Oberdörster J. Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. *Environ. Health Perspect.* 2005;113(7):823.

48.     Knibbs LD, Cole-Hunter T, Morawska L. A review of commuter exposure to ultrafine particles and its health effects. *Atmos. Environ.* 2011;45:2611-2622.

49.     Brunekreef B, Holgate ST. Air pollution and health. *The Lancet.* 2002;360(9341):1233-1242.

50.     Blair SN, Morris JN. Healthy hearts--and the universal benefits of being physically active: Physical activity and health. *Ann. Epidemiol.* 2009;19(4):253-256.

51.     Shiroma EJ, Lee I. Physical activity and cardiovascular health: lessons learned from epidemiological studies across age, gender, and race/ethnicity. *Circulation.* 2010;122(7):743.

52.     Warburton DER, Nicol CW, Bredin SSD. Health benefits of physical activity: the evidence. *Can. Med. Assoc. J.* 2006;174(6):801.

**Tables**

Table **1** - Characteristics of participants

| CHARACTERISTIC [n = 153 (28% female)] | MEAN | SD | MIN / MAX |
|---|---|---|---|
| Age (*years*) | 41 | 11 | 19 / 64 |
| Single Trip Distance (*km*) | 11 | 7 | 4 / 32 |
| Single Trip Duration (*min*) | 31 | 15 | 10 / 65 |
| Return Trips (*per week*) | 4 | 1 | 2 / 5 |
| Inbound Start Time (*24 hr*) | 07:15 | 0:56 | 05:30 / 10:00 |
| Outbound Start Time (*24 hr*) | 17:10 | 1:00 | 15:30 / 19:00 |

Participants of this project were adults and frequent bicycle commuters of the Brisbane inner-city region (i.e., those completing ≥ two return trips in a five week-day period to a destination within a one kilometre radius of the Brisbane Central Business District). A total of 153 questionnaires were completed [with 43 (28%) by females].

Table **2** – Acute respiratory symptoms of bicycle commuters as the total group and the sub-groups of gender

| RESPONSE | TOTAL [n = 153 (100%)] | | | GENDER | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Female* [n = 43 (28%)] | | | *Male* [n = 110 (72%)] | | |
| | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** |
| **Offensive Odour** | 1.4 ±0.1 | 2.7 ±0.1 | 1.4 ±0.1 | 1.5 ±0.1 | 2.8 ±0.1 | 1.5 ±0.1 | 1.4 ±0.1 | 2.7 ± 0.1 | 1.4 ±0.1 |
| **Nasopharyngeal Irritation** | 1.4 ±0.1 | 2.1 ±0.1 | 1.7 ±0.1 | 1.5 ±0.1 | 2.3[**] ±0.1 | 2.1[**] ±0.3 | 1.4 ±0.1 | 2.0 ±0.1 | 1.6 ±0.1 |
| **Tussis** | 1.3 ±0.1 | 2.0 ±0.11 | 1.7 ±0.1 | 1.4 ±0.1 | 2.0 ±0.2 | 1.8 ±0.1 | 1.3 ±0.1 | 1.9 ±0.1 | 1.6 ±0.1 |
| **Chest Tightness** | 1.2 ±0.1 | 1.5 ±0.1 | 1.3 ±0.1 | 1.3 ±0.1 | 1.5 ±0.1 | 1.3 ±0.1 | 1.2 ±0.0 | 1.5 ±0.1 | 1.3 ±0.1 |
| **Chest Wheeze** | 1.1 ±0.1 | 1.5 ±0.1 | 1.3 ±0.1 | 1.3 ±0.1 | 1.6[*] ±0.1 | 1.4 ±0.0 | 1.1 ±0.0 | 1.4 ±0.1 | 1.3 ±0.1 |

Values are group mean ± standard deviation (SD) [*] $p < 0.05$, [**] $p < 0.01$, higher frequency than Male.

Participants [n = participant number (percentage of total cohort)] reported the perception of air pollution and frequency of acute respiratory symptoms one hour before (Pre), during (In) and one hour after (Post) their standard bicycle commute, using the common 5-point scale (as: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High).

Table **3** - Perceptions and preferences of bicycle commuters as the total group and the sub-groups of gender

| RESPONSE | TOTAL | GENDER | |
|---|---|---|---|
| | | *Female* | *Male* |
| | [n = 153 (100%)] | [n = 43 (28%)] | [n = 110 (72%)] |
| **Perceived Exposure (%Yes)** | 80 | 91[*] | 76 |
| **Re-route Willing (%Yes)** | 68 | 80[*] | 63 |
| **Respirator Willing (%Yes)** | 75 | 77 | 74 |
| **PROX (% Commute)** | 52 ± 2.8 | 46 ± 3.4 | 54 ± 2.6 |

Values are group mean ± standard deviation (SD). * $p < 0.05$, higher positive response than Male. %Yes = proportion of positive response from Total / Gender sub-groups. PROX = percentage of the time spent proximal to motorised traffic [as the product of their trip duration, frequency and use of motorised traffic corridors (being the proportion of route on-road, or route shared with motorised traffic) for their current typical bicycle commute]. Participants [n = participant number (percentage of total cohort)] reported their perception of in-commute exposure to air pollution and their willingness to use risk management strategies of commute re-routing or respirator use.

Table **4** – Acute respiratory symptoms of bicycle commuters according to sub-groups of health status

| RESPONSE | HEALTH STATUS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Healthy* [n = 93 (62%)] | | | *Smoking History* [n = 24 (15%)] | | | *Respiratory Disorder* [n = 36 (23%)] | | |
| | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** |
| **Offensive Odour** | 1.3 ±0.1 | 2.7 ±0.1 | 1.4 ±0.1 | 1.5 ±0.1 | $2.4^{+}$ ±0.2 | 1.5 ±0.1 | 1.5 ±0.2 | 2.8 ±0.2 | 1.5 ±0.1 |
| **Nasopharyngeal Irritation** | 1.3 ±0.1 | $2.0^{*}$ ±0.1 | $1.6^{*}$ ±0.1 | 1.6 ±0.2 | $2.0^{*}$ ±0.2 | 1.7 ±0.2 | 1.4 ±0.1 | $2.2^{\#,\$}$ ±0.2 | $2.0^{\$}$ ±0.2 |
| **Tussis** | 1.3 ±0.1 | $1.8^{*}$ ±0.1 | $1.5^{*}$ ±0.1 | 1.5 ±0.2 | $2.0^{*}$ ±0.3 | $1.9^{*}$ ±0.3 | 1.5 ±0.1 | $2.4^{\#,\$}$ ±0.2 | $2.1^{\#,\$}$ ±0.2 |
| **Chest Tightness** | 1.2 ±0.0 | 1.4 ±0.1 | 1.2 ±0.1 | 1.3 ±0.1 | $1.6^{*}$ ±0.2 | 1.4 ±0.1 | 1.3 ±0.1 | $1.8^{\#,\$}$ ±0.2 | $1.5^{\#}$ ±0.1 |
| **Chest Wheeze** | 1.1 ±0.1 | 1.4 ±0.1 | 1.2 ±0.1 | 1.2 ±0.1 | 1.5 ±0.2 | 1.4 ±0.2 | 1.3 ±0.1 | $1.8^{\#,\$}$ ±0.2 | $1.6^{\#}$ ±0.1 |

Values are group mean ± standard deviation (SD) $^{*}p < 0.05$, higher symptom frequency than pre-commute (Pre). $^{\#}p < 0.05$, $^{\#\#}p < 0.01$, higher frequency than Healthy. $^{+}p < 0.05$, lower frequency than Healthy. Participants [n = participant number (percentage of total cohort)] reported the frequency of air pollution perception and acute respiratory symptoms of increasing severity one hour before (Pre), during (In) and one hour after (Post) their standard bicycle commute, using the common 5-point scale (as: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High). Smoking History is defined as a participant who ceased habitual smoking greater than 24 months previously but is otherwise healthy. Respiratory Disorder is defined as a previous diagnosis of a condition / disease / disorder of the airways or lungs.

Table **5** – Perceptions and preferences for bicycle commuters according to sub-groups of health status

| RESPONSE | HEALTH STATUS | | |
|---|---|---|---|
| | *Healthy* | *Smoking History* | *Respiratory Disorder* |
| | [n = 93 (62%)] | [n = 24 (15%)] | [n = 36 (23%)] |
| **Perceived Exposure (% Yes)** | 82 | 68[*] | 72 |
| **Re-route Willing (% Yes)** | 68 | 59 | 65 |
| **Respirator Willing (% Yes)** | 75 | 71 | 73 |
| **PROX (% Commute)** | 55 ± 2.6 | 44 ± 5.2 | 45 |

Values are group mean ± standard deviation (SD).  * $p < 0.05$, lower positive response than Healthy. %Yes = proportion of positive response from Health Status sub-groups. PROX = percentage of the time spent proximal to motorised traffic [as the product of their trip duration, frequency and use of motorised traffic corridors (being the proportion of route on-road, or route shared with motorised traffic) for their current typical bicycle commute]. Participants [n = participant number (percentage of total cohort)] reported their in-commute perception of exposure to air pollution and their willingness to use risk management strategies of commute re-routing or respirator use. Smoking History is defined as a participant who ceased habitual smoking greater than 24 months previously but is otherwise healthy. Respiratory Disorder is defined as a previous diagnosis of a condition / disease / disorder of the airways or lungs.

**REFERENCES**

1.      de Nazelle A, Nieuwenhuijsen M. Integrated health impact assessment of cycling. *Occup. Environ. Med.* 2010;67(2):76.

2.      de Nazelle A, Nieuwenhuijsen MJ, Antó, JM, Brauer, M, Briggs, D, Braun-Fahrlander, C, … Lebret, E. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. *Environment International.* 2011;37(4):766.

3.      Woodcock J, Edwards P, Tonne C, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet.* 2009;374(9705):1930-1943.

4.      Rabl A, de Nazelle A. Benefits of shift from car to active transport. *Transport Policy.* 2012;19(1):121-131.

5.      de Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? *Environ. Health Perspect.* 2010;118(8):1109.

6.      Weichenthal S, Kulka R, Dubeau A, Martin C, Wang D, Dales R. Traffic-related air pollution and acute changes in heart rate variability and respiratory function in urban cyclists. *Environ. Health Perspect.* 2011;119(10):1373–1378.

7.      Int Panis L, de Geus B, Vandenbulcke G, et al. Exposure to particulate matter in traffic: A comparison of cyclists and car passengers. *Atmos. Environ.* 2010;44(19):2263-2270.

8.      McNabola A, Broderick BM, Gill LW. Relative exposure to fine particulate matter and VOCs between transport microenvironments in Dublin: Personal exposure and uptake. *Atmos. Environ.* 2008;42(26):6496-6512.

9.      Zuurbier M, Hoek G, Oldenwening M, et al. Commuters exposure to particulate matter air pollution is affected by mode of transport, fuel type, and route. *Environ. Health Perspect.* 2010;118(6):783.

10.     Zuurbier M, Hoek G, Oldenwening M, Meliefste K, Van den Hazel P, Brunekreef B. Acute health effects of commuters' exposure to air pollution. *Epidemiology.* 2009;20(6):S197.

11.     Adams HS, Nieuwenhuijsen MJ, Colvile RN. Determinants of fine particle (PM2. 5) personal exposure levels in transport microenvironments, London, UK. *Atmos. Environ.* 2001;35(27):4557-4566.

12.     Briggs DJ, de Hoogh K, Morris C, Gulliver J. Effects of travel mode on exposures to particulate air pollution. *Environment International.* 2008;34(1):12-22.

13.     Kaur S, Nieuwenhuijsen MJ, Colvile RN. Pedestrian exposure to air pollution along a major road in Central London, UK. *Atmos. Environ.* 2005;39(38):7307-7320.

14.     Kaur S, Nieuwenhuijsen MJ, Colvile RN. Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. *Atmos. Environ.* 2007;41(23):4781-4810.

15.     Zhou Y, Levy J. Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC Public Health.* 2007;7(1):89.

16. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ: British Medical Journal.* 2011;343.

17. Künzli N, Jerrett M, Garcia-Esteban R, et al. Ambient air pollution and the progression of atherosclerosis in adults. *PLoS One.* 2010;5(2):e9096.

18. Lee K, Yanagisawa Y, Spengler JD, Nakai S. Carbon monoxide and nitrogen dioxide exposures in indoor ice skating rinks. *J. Sports Sci.* 1994;12:279-279.

19. Ghio AJ, Devlin RB. Inflammatory lung injury after bronchial instillation of air pollution particles. *Am. J. Respir. Crit. Care Med.* 2001;164(4):704.

20. Belanger K, Gent JF, Triche EW, Bracken MB, Leaderer BP. Association of indoor nitrogen dioxide exposure with respiratory symptoms in children with asthma. *American journal of respiratory and critical care medicine.* 2006;173(3):297.

21. Johns DO, Svendsgaard D, Linn WS. Analysis of the concentration-respiratory response among asthmatics following controlled short-term exposures to sulfur dioxide. *Inhal. Toxicol.* 2010;22(14):1184-1193.

22. Wilhelm M, Qian L, Ritz B. Outdoor air pollution, family and neighborhood environment, and asthma in LA FANS children. *Health & Place.* 2009;15(1):25-36.

23. Jarvis D, Chinn S, Luczynska C, Burney P. Association of respiratory symptoms and lung function in young adults with use of domestic gas appliances. *The Lancet.* 1996;347(8999):426-431.

24. Kjærgaard T, Cvancarova M, Steinsvåg SK. Cigarette smoking and self-assessed upper airway health. *Eur. Arch. Otorhinolaryngol.* 2011;268(2):219-226.

25. van der Zee SC, Hoek G, Boezen MH, Schouten JP, van Wijnen JH, Brunekreef B. Acute effects of air pollution on respiratory health of 50-70 yr old adults. *Eur. Respir. J.* 2000;15(4):700.

26. Aatamila M, Verkasalo PK, Korhonen MJ, et al. Odour annoyance and physical symptoms among residents living near waste treatment centres. *Environ. Res.* 2010;111(1):164-170.

27. Stenlund T, Liden E, Andersson K, Garvill J, Nordin S. Annoyance and health symptoms and their influencing factors: a population-based air pollution intervention study. *Public Health.* 2009;123(4):339-345.

28. Badland HM, Duncan MJ. Perceptions of air pollution during the work-related commute by adults in Queensland, Australia. *Atmos. Environ.* 2009;43(36):5791-5795.

29. ATS. What constitutes an adverse health effect of air pollution? *Am. J. Respir. Crit. Care Med.* 2000;161:665-673.

30. Rudell B, Ledin M, Hammarström U, Stjernberg N, Lundbäck B, Sandström T. Effects on symptoms and lung function in humans experimentally exposed to diesel exhaust. *Occup. Environ. Med.* 1996;53(10):658.

31. Council) BBC. Bikeway and shared pathway maps. 2010; http://www.brisbane.qld.gov.au/traffic-transport/cycling/bikeway-and-shared-pathway-maps/index.htm. Accessed 30 March, 2010.

32. Cone JE, Shusterman D. Health effects of indoor odorants. *Environ Health Persp.* 1991;95:53.

33. Lercher P, Schmitzberger R, Kofler W. Perceived traffic air pollution, associated behavior and health in an alpine area. *Sci. Total Environ.* 1995;169(1-3):71-74.

34. Shusterman D. Community health and odor pollution regulation. *Am. J. Public Health.* 1992;82(11):1566.

35. Paustenbach DJ, Gaffney SH. The role of odor and irritation, as well as risk perception, in the setting of occupational exposure limits. *Int. Arch. Occup. Environ. Health.* 2006;79(4):339-342.

36. Dalton P. Cognitive influences on health symptoms from acute chemical exposure. *Health Psychol.* 1999;18:579-590.

37. Righi E, Aggazzotti G, Fantuzzi G, Ciccarese V, Predieri G. Air quality and well-being perception in subjects attending university libraries in Modena (Italy). *Sci. Total Environ.* 2002;286(1-3):41-50.

38. Hirsch T, Weiland SK, Von Mutius E, et al. Inner city air pollution and respiratory health and atopy in children. *Eur. Respir. J.* 1999;14(3):669-677.

39. Simoni M, Annesi-Maesano I, Sigsgaard T, et al. School air quality related to dry cough, rhinitis and nasal patency in children. *Eur. Respir. J.* 2010;35(4):742.

40. Nikolopoulou M, Kleissl J, Linden P, Lykoudis S. Pedestrians perception of environmental stimuli through field surveys: Focus on particulate pollution. *The Science of the total environment.* 2011;409(13):2493-2502.

41.     Nel AE, Diaz-Sanchez D, Ng D, Hiura T, Saxon A. Enhancement of allergic inflammation by the interaction between diesel exhaust particles and the immune system. *J. Allergy Clin. Immunol.* 1998;102(4):539-554.

42.     Ayoko G, Jamriska M, Jayaratne R, Morawska L. Air pollution levels measured at traffic hot spots: Brisbane urban corridor study 2005. In Wise, Convention (Ed.) *Proceedings of 17th International Clean Air and Environment Conference*, CASANZ (Clean Air Society of Australia & New Zealand), Hobart, Tasmania, pp. 1-7.

43.     Belanger E, Kielb C, Lin S. Asthma hospitalization rates among children, and school building conditions, by New York state school districts, 1991-2001. *J. Sch. Health.* 2006;76(8):408-413.

44.     Pribyl CR, Racca J. Toxic gas exposures in ice arenas. *Clin. J. Sport Med.* 1996;6(4):232.

45.     DDoEaR. Queensland 2010 Air Monitoring Report. 2011; http://www.derm.qld.gov.au/air/pdf/reports/2010-air-monitoring-report.pdf. Accessed 16 June, 2011.

46.     Bräuner EV, Møller P, Barregard L, et al. Exposure to ambient concentrations of particulate air pollution does not influence vascular function or inflammatory pathways in young healthy individuals. *Particle and Fibre Toxicology.* 2008;5(1):13.

47.     Oberdörster G, Oberdörster E, Oberdörster J. Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. *Environ. Health Perspect.* 2005;113(7):823.

48.     Knibbs LD, Cole-Hunter T, Morawska L. A review of commuter exposure to ultrafine particles and its health effects. *Atmos. Environ.* 2011;45:2611-2622.

49.     Brunekreef B, Holgate ST. Air pollution and health. *The Lancet.* 2002;360(9341):1233-1242.

50.     Blair SN, Morris JN. Healthy hearts--and the universal benefits of being physically active: Physical activity and health. *Ann. Epidemiol.* 2009;19(4):253-256.

51.     Shiroma EJ, Lee I. Physical activity and cardiovascular health: lessons learned from epidemiological studies across age, gender, and race/ethnicity. *Circulation.* 2010;122(7):743.

52.     Warburton DER, Nicol CW, Bredin SSD. Health benefits of physical activity: the evidence. *Can. Med. Assoc. J.* 2006;174(6):801.

**TABLES**

Table **1** - Characteristics of participants

| CHARACTERISTIC [n = 153 (28% female)] | MEAN | SD | MIN / MAX |
|---|---|---|---|
| Age (*years*) | 41 | 11 | 19 / 64 |
| Single Trip Distance (*km*) | 11 | 7 | 4 / 32 |
| Single Trip Duration (*min*) | 31 | 15 | 10 / 65 |
| Return Trips (*per week*) | 4 | 1 | 2 / 5 |
| Inbound Start Time (*24 hr*) | 07:15 | 0:56 | 05:30 / 10:00 |
| Outbound Start Time (*24 hr*) | 17:10 | 1:00 | 15:30 / 19:00 |

Participants of this project were adults and frequent bicycle commuters of the Brisbane inner-city region (i.e., those completing ≥ two return trips in a five week-day period to a destination within a one kilometre radius of the Brisbane Central Business District). A total of 153 questionnaires were completed [with 43 (28%) by females].

Table **2** – Acute respiratory symptoms of bicycle commuters as the total group and the sub-groups of gender

| RESPONSE | TOTAL [n = 153 (100%)] | | | GENDER | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | *Female* [n = 43 (28%)] | | | *Male* [n = 110 (72%)] | | |
| | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** |
| **Offensive Odour** | 1.4 ±0.1 | 2.7 ±0.1 | 1.4 ±0.1 | 1.5 ±0.1 | 2.8 ±0.1 | 1.5 ±0.1 | 1.4 ±0.1 | 2.7 ± 0.1 | 1.4 ±0.1 |
| **Nasopharyngeal Irritation** | 1.4 ±0.1 | 2.1 ±0.1 | 1.7 ±0.1 | 1.5 ±0.1 | 2.3** ±0.1 | 2.1** ±0.3 | 1.4 ±0.1 | 2.0 ±0.1 | 1.6 ±0.1 |
| **Tussis** | 1.3 ±0.1 | 2.0 ±0.11 | 1.7 ±0.1 | 1.4 ±0.1 | 2.0 ±0.2 | 1.8 ±0.1 | 1.3 ±0.1 | 1.9 ±0.1 | 1.6 ±0.1 |
| **Chest Tightness** | 1.2 ±0.1 | 1.5 ±0.1 | 1.3 ±0.1 | 1.3 ±0.1 | 1.5 ±0.1 | 1.3 ±0.1 | 1.2 ±0.0 | 1.5 ±0.1 | 1.3 ±0.1 |
| **Chest Wheeze** | 1.1 ±0.1 | 1.5 ±0.1 | 1.3 ±0.1 | 1.3 ±0.1 | 1.6* ±0.1 | 1.4 ±0.0 | 1.1 ±0.0 | 1.4 ±0.1 | 1.3 ±0.1 |

Values are group mean ± standard deviation (SD) * $p < 0.05$, ** $p < 0.01$, higher frequency than Male.

Participants [n = participant number (percentage of total cohort)] reported the perception of air pollution and frequency of acute respiratory symptoms one hour before (Pre), during (In) and one hour after (Post) their standard bicycle commute, using the common 5-point scale (as: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High).

Table **3** - Perceptions and preferences of bicycle commuters as the total group and the sub-groups of gender

| RESPONSE | TOTAL | GENDER | |
|---|---|---|---|
| | | *Female* | *Male* |
| | [n = 153 (100%)] | [n = 43 (28%)] | [n = 110 (72%)] |
| **Perceived Exposure (%Yes)** | 80 | 91[*] | 76 |
| **Re-route Willing (%Yes)** | 68 | 80[*] | 63 |
| **Respirator Willing (%Yes)** | 75 | 77 | 74 |
| **PROX (% Commute)** | 52 ± 2.8 | 46 ± 3.4 | 54 ± 2.6 |

Values are group mean ± standard deviation (SD). * $p < 0.05$, higher positive response than Male. %Yes = proportion of positive response from Total / Gender sub-groups. PROX = percentage of the time spent proximal to motorised traffic [as the product of their trip duration, frequency and use of motorised traffic corridors (being the proportion of route on-road, or route shared with motorised traffic) for their current typical bicycle commute]. Participants [n = participant number (percentage of total cohort)] reported their perception of in-commute exposure to air pollution and their willingness to use risk management strategies of commute re-routing or respirator use.

Table **4** – Acute respiratory symptoms of bicycle commuters according to sub-groups of health status

| RESPONSE | HEALTH STATUS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Healthy* [n = 93 (62%)] | | | *Smoking History* [n = 24 (15%)] | | | *Respiratory Disorder* [n = 36 (23%)] | | |
| | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** | **Pre** | **In** | **Post** |
| **Offensive Odour** | 1.3 ±0.1 | 2.7 ±0.1 | 1.4 ±0.1 | 1.5 ±0.1 | $2.4^{+}$ ±0.2 | 1.5 ±0.1 | 1.5 ±0.2 | 2.8 ±0.2 | 1.5 ±0.1 |
| **Nasopharyngeal Irritation** | 1.3 ±0.1 | $2.0^{*}$ ±0.1 | $1.6^{*}$ ±0.1 | 1.6 ±0.2 | $2.0^{*}$ ±0.2 | 1.7 ±0.2 | 1.4 ±0.1 | $2.2^{\#,\$}$ ±0.2 | $2.0^{\$}$ ±0.2 |
| **Tussis** | 1.3 ±0.1 | $1.8^{*}$ ±0.1 | $1.5^{*}$ ±0.1 | 1.5 ±0.2 | $2.0^{*}$ ±0.3 | $1.9^{*}$ ±0.3 | 1.5 ±0.1 | $2.4^{\#,\$}$ ±0.2 | $2.1^{\#,\$}$ ±0.2 |
| **Chest Tightness** | 1.2 ±0.0 | 1.4 ±0.1 | 1.2 ±0.1 | 1.3 ±0.1 | $1.6^{*}$ ±0.2 | 1.4 ±0.1 | 1.3 ±0.1 | $1.8^{\#,\$}$ ±0.2 | $1.5^{\#}$ ±0.1 |
| **Chest Wheeze** | 1.1 ±0.1 | 1.4 ±0.1 | 1.2 ±0.1 | 1.2 ±0.1 | 1.5 ±0.2 | 1.4 ±0.2 | 1.3 ±0.1 | $1.8^{\#,\$}$ ±0.2 | $1.6^{\#}$ ±0.1 |

Values are group mean ± standard deviation (SD) $^{*}p < 0.05$, higher symptom frequency than pre-commute (Pre). $^{\#}p < 0.05$, $^{\#\#}p < 0.01$, higher frequency than Healthy. $^{+}p < 0.05$, lower frequency than Healthy. Participants [n = participant number (percentage of total cohort)] reported the frequency of air pollution perception and acute respiratory symptoms of increasing severity one hour before (Pre), during (In) and one hour after (Post) their standard bicycle commute, using the common 5-point scale (as: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High). Smoking History is defined as a participant who ceased habitual smoking greater than 24 months previously but is otherwise healthy. Respiratory Disorder is defined as a previous diagnosis of a condition / disease / disorder of the airways or lungs.

Table **5** – Perceptions and preferences for bicycle commuters according to sub-groups of health status

| RESPONSE | HEALTH STATUS | | |
|---|---|---|---|
| | *Healthy* | *Smoking History* | *Respiratory Disorder* |
| | [n = 93 (62%)] | [n = 24 (15%)] | [n = 36 (23%)] |
| **Perceived Exposure (% Yes)** | 82 | 68[*] | 72 |
| **Re-route Willing (% Yes)** | 68 | 59 | 65 |
| **Respirator Willing (% Yes)** | 75 | 71 | 73 |
| **PROX (% Commute)** | 55 ± 2.6 | 44 ± 5.2 | 45 |

Values are group mean ± standard deviation (SD). * $p < 0.05$, lower positive response than Healthy. %Yes = proportion of positive response from Health Status sub-groups. PROX = percentage of the time spent proximal to motorised traffic [as the product of their trip duration, frequency and use of motorised traffic corridors (being the proportion of route on-road, or route shared with motorised traffic) for their current typical bicycle commute]. Participants [n = participant number (percentage of total cohort)] reported their in-commute perception of exposure to air pollution and their willingness to use risk management strategies of commute re-routing or respirator use. Smoking History is defined as a participant who ceased habitual smoking greater than 24 months previously but is otherwise healthy. Respiratory Disorder is defined as a previous diagnosis of a condition / disease / disorder of the airways or lungs.