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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 \(^1\text{-}^4\). 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) \(^7\text{-}^10\) and closer proximity to motorised traffic emissions \(^6,^8,^{11\text{-}15}\). 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 \(^20\text{-}^22\), 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\textsuperscript{29} and previous research\textsuperscript{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 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 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 ≥ 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 ≥ 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).
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 \( (p < 0.05; \text{Table 4}) \). 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 \( (p < 0.05; \text{Table 4}) \). Sub-groups of smoking history or respiratory disorder showed no significant differences of PROX (Table 5).

**INSERT TABLE 4 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, subgroups 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 (NO₂), 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 NO2 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 NO2
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
NO2 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 NO2 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\textsuperscript{42}. Adults with asthma are twice as sensitive as adults without asthma to short-term exposures of NO\textsubscript{2}, however significantly increased airway resistance (due to inflammation) has not been observed below 500 ppb\textsuperscript{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\textsuperscript{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\textsubscript{2} and PM) compared to previously investigated regions\textsuperscript{18,43,44}.

During the period of the current project, in south-east Queensland (SE QLD; surrounding Brisbane, Australia) ambient PM\textsubscript{10} and PM\textsubscript{2.5} (particulate matter with diameters of 10 and 2.5 micrometres, respectively) maximum daily mean particle mass concentrations were 37 and 19 \(\mu\text{g/m}^3\), respectively\textsuperscript{45}. Previous recordings of roadside PM\textsubscript{10} indicated one-hour mean concentrations of 25 \(\pm\) 13 \(\mu\text{g/m}^3\) and a maximum of 90 \(\mu\text{g/m}^3\), associated with high traffic counts and large proportions of heavy duty vehicles\textsuperscript{42}. PM\textsubscript{2.5} one-hour mean concentrations of 21 \(\pm\) 11 \(\mu\text{g/m}^3\) and a maximum of 195 \(\mu\text{g/m}^3\) 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\textsuperscript{42}. Exposure to particulate matter (PM) can induce inflammation in the airways and exacerbate respiratory disorders\textsuperscript{19,41}. However, short-term exposure to PM\textsubscript{10} and PM\textsubscript{2.5} at regionalised outdoor mass concentrations of 14 \(\pm\) 7 and 11 \(\pm\) 5 \(\mu\text{g/m}^3\), respectively, has not been associated with detrimental health effects in young, healthy participants performing exercise\textsuperscript{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\textsuperscript{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\textsuperscript{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\cite{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**


Table 1 - Characteristics of participants

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</table>

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<td></td>
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<td></td>
<td>Pre</td>
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</tr>
<tr>
<td>Offensive Odour</td>
<td>1.4 ±0.1</td>
<td>2.7 ±0.1</td>
</tr>
<tr>
<td>Nasopharyngeal Irritation</td>
<td>1.4 ±0.1</td>
<td>2.1 ±0.1</td>
</tr>
<tr>
<td>Tussis</td>
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</tr>
<tr>
<td>Chest Tightness</td>
<td>1.2 ±0.1</td>
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</tr>
<tr>
<td>Chest Wheeze</td>
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<td>1.5 ±0.1</td>
</tr>
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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

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</tr>
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<td>Re-route Willing (%Yes)</td>
<td>68</td>
<td>80*</td>
</tr>
<tr>
<td>Respirator Willing (%Yes)</td>
<td>75</td>
<td>77</td>
</tr>
<tr>
<td>PROX (% Commute)</td>
<td>52 ± 2.8</td>
<td>46 ± 3.4</td>
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Table 4 – Acute respiratory symptoms of bicycle commuters according to sub-groups of health status

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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Healthy [n = 93 (62%)]</td>
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<tr>
<td></td>
<td>Smoking History [n = 24 (15%)]</td>
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<td></td>
<td>Respiratory Disorder [n = 36 (23%)]</td>
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<td>In</td>
<td>Post</td>
<td>Pre</td>
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<td>Pre</td>
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<td>Post</td>
</tr>
<tr>
<td>Offensive Odour</td>
<td>1.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
<td>1.4 ± 0.1</td>
<td>1.5 ± 0.1</td>
<td>2.4* ± 0.2</td>
<td>1.5 ± 0.1</td>
<td>1.5 ± 0.2</td>
<td>2.8 ± 0.2</td>
<td>1.5 ± 0.1</td>
</tr>
<tr>
<td>Nasopharyngeal Irritation</td>
<td>1.3 ± 0.1</td>
<td>2.0* ± 0.1</td>
<td>1.6 ± 0.1</td>
<td>1.6 ± 0.2</td>
<td>2.0* ± 0.2</td>
<td>1.7 ± 0.2</td>
<td>1.4 ± 0.2</td>
<td>2.2** ± 0.2</td>
<td>2.0**</td>
</tr>
<tr>
<td>Tussis</td>
<td>1.3 ± 0.1</td>
<td>1.8* ± 0.1</td>
<td>1.5* ± 0.1</td>
<td>1.5 ± 0.2</td>
<td>2.0* ± 0.3</td>
<td>1.9* ± 0.3</td>
<td>1.5 ± 0.3</td>
<td>2.4** ± 0.3</td>
<td>2.1**</td>
</tr>
<tr>
<td>Chest Tightness</td>
<td>1.2 ± 0.0</td>
<td>1.4 ± 0.1</td>
<td>1.2 ± 0.1</td>
<td>1.3 ± 0.2</td>
<td>1.6* ± 0.1</td>
<td>1.4 ± 0.2</td>
<td>1.3 ± 0.2</td>
<td>1.8** ± 0.2</td>
<td>1.5*</td>
</tr>
<tr>
<td>Chest Wheeze</td>
<td>1.1 ± 0.1</td>
<td>1.4 ± 0.1</td>
<td>1.2 ± 0.1</td>
<td>1.5 ± 0.2</td>
<td>1.4 ± 0.2</td>
<td>1.3 ± 0.2</td>
<td>1.3 ± 0.2</td>
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<td>1.6*</td>
</tr>
</tbody>
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<th>Smoking History</th>
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</tr>
</thead>
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<tr>
<td></td>
<td>Healthy</td>
<td>[n = 93 (62%) ]</td>
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</tr>
<tr>
<td>Perceived Exposure (% Yes)</td>
<td>82</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td>Re-route Willing (% Yes)</td>
<td>68</td>
<td>59</td>
<td>65</td>
</tr>
<tr>
<td>Respirator Willing (% Yes)</td>
<td>75</td>
<td>71</td>
<td>73</td>
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<tr>
<td>PROX (% Commute)</td>
<td>55 ± 2.6</td>
<td>44 ± 5.2</td>
<td>45</td>
</tr>
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</tr>
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</tr>
<tr>
<td>Offensive Odour</td>
<td>1.4</td>
<td>2.7</td>
</tr>
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<td></td>
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