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# Radon, an Invisible Killer in Canadian Homes: Perceptions of Ottawa-Gatineau Residents

--Manuscript Draft--

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| **Funding Information:** | Faculty of Health Sciences, University of Ottawa (7160957) — Dr. SELIM M. KHAN |
| **Abstract:** | ABSTRACT<br><br>BACKGROUND: Canadians have reason to care about indoor air quality as they spend over 90% of the time indoors. Although indoor radon causes more deaths than any other environmental hazard, 55% of Canadians have heard of it, and only 6% have undertaken action. The gap between residents' risk awareness and adoption of actual protective behaviour presents a challenge to public health practitioners. Residents' perception of the risk should inform health communication that targets motivation for action. In Canada, research about the public perception of radon health risk is lacking. OBJECTIVE: To describe residents' perceptions of radon health risks and evaluate how perceptions correlate with protection behaviours applying a theoretical lens. METHOD(S): We conducted a mixed online and face to face survey (N=557) with both homeowners and tenants in Ottawa-Gatineau census metropolitan area. Descriptive, correlation and regression analyses addressed the research questions. RESULTS: Compared to the gravity of the risk, public perception remained low. While 32% of residents expressed some concern about radon health risk, 12% of them tested and only 3% mitigated their homes for radon. Residents' perceptions of the probability and severity of the risk, social influence, care for children, and smoking in home correlated significantly with their intention to test; these factors also predicted their behaviours for testing and mitigation. CONCLUSIONS: Health risk communication programs need to consider the affective aspects of risk perception in addition to rational cognition to improve protection behaviours. A qualitative study can explore the reasons behind the gap between testing and mitigation.<br><br>Keywords: Air Pollution; Indoor; Radon; Risk; Perception; Canada.<br><br>Résumé<br><br>CONTEXTE : Les Canadiens ont de bonnes raisons de se préoccuper de la qualité de l'air intérieur, car ils passent plus de 90% de leur temps à l'intérieur. Bien que le radon domiciliaire (RD) cause plus de décès que tout autre risques environnemental, 55% des Canadiens en ont déjà entendu parler, tandis que seulement 6% ont pris des mesures concrètes pour l'éradiquer. L'écart entre la sensibilisation aux risques et la prise de mesures de protection réelles par les résidents constitue un défi pour les professionnels de la santé publique. La perception des résidents face aux risques associés au RD devrait guider la communication en matière de santé pour cibler la motivation. Au Canada, très peu d'études portant sur les perceptions de la population face aux risques associés au RD ont été réalisées. OBJECTIFS : Décrire les perceptions qu'entretiennent les résidents face aux risques pour la santé associée au RD et évaluer comment ces perceptions sont corrélées aux comportements de protection, notamment en appliquant la théorie de la motivation et de la protection. MÉTHODES : Nous avons réalisé une enquête mixte en ligne et en personne (n = 557) auprès de propriétaires et de locataires de la région d'Ottawa-Gatineau. Des analyses descriptives, corrélationnelles et des analyses de régressions ont été effectuées en fonction de nos questions de recherche. RÉSULTATS : En comparaison à la gravité |

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| | Raywat Deonandan, MSc, Ph.D |
| **Order of Authors Secondary Information:** | |
| **Author Comments:** | This article reports mostly the quantitative results of a mixed methods study and is a part of my Ph.D. (Population Health) thesis at the University of Ottawa, Health Sciences Faculty.<br><br>This manuscript has not been published and is not under consideration for publication elsewhere.<br><br>Although the summary of these findings was presented in the 7th annual radon conference of CARST 2018 in April in Ottawa, I did not authorize any publication out of that presentation.<br><br>We (authors) have no conflicts of interest to disclose.<br><br>We are ready to provide the data for an editorial review.<br><br>There is no copyright issue as I checked with the University of Ottawa's Copyright office, and all contributions are duly referenced and acknowledged. |
| **Response to Reviewers:** | Dear Reviewers,<br><br>Thank you very much for taking your time to review our paper and provide with valuable comments and suggestions. These helped a lot in improving the article. |

I am copying the issues raised by you, keeping them in the same order and indicating our responses in the brackets. In most of the cases, we agreed, accepted your suggestions and revised the paper accordingly. However, in a few instances where there was disagreement, we duly explained the rationales. All the changes we made are indicated with the justifications in the corresponding line number of the revised text as well. Kindly note that for revising and paraphrasing, line numbers may change in some places, but the responses are always linked precisely to the points indicated.

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# Radon, an Invisible Killer in Canadian Homes: Perceptions of Ottawa-Gatineau Residents

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**Short running title**: Radon Health Risk Perception;
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**Radon, an Invisible Killer in Canadian Homes: Perceptions of Ottawa-Gatineau Residents**


## ABSTRACT

**BACKGROUND:** Canadians have reason to care about indoor air quality as they spend over 90% of the time indoors. Although indoor radon causes more deaths than any other environmental hazard, 55% of Canadians have heard of it, and only 6% have undertaken action. The gap between residents' risk awareness and adoption of actual protective behaviour presents a challenge to public health practitioners. Residents' perception of the risk should inform health communication that targets motivation for action. In Canada, research about the public perception of radon health risk is lacking. **OBJECTIVE:** To describe residents' perceptions of radon health risks and evaluate how perceptions correlate with protection behaviours applying a theoretical lens. **METHOD(S)**: We conducted a mixed online and face to face survey (N=557) with both homeowners and tenants in Ottawa-Gatineau census metropolitan area. Descriptive, correlation and regression analyses addressed the research questions. **RESULTS:** Compared to the gravity of the risk, public perception remained low. While 32% of residents expressed some concern about radon health risk, 12% of them tested and only 3% mitigated their homes for radon. Residents' perceptions of the probability and severity of the risk, social influence, care for children, and smoking in home correlated significantly with their intention to test; these factors also predicted their behaviours for testing and mitigation. **CONCLUSIONS:** Health risk communication programs need to consider the affective aspects of risk perception in addition to rational cognition to improve protection behaviours. A qualitative study can explore the reasons behind the gap between testing and mitigation.



***Keywords***: Air Pollution, Indoor, Radon, Risk, Perception, Canada.



## Résumé

**CONTEXTE** : Les Canadiens ont de bonnes raisons de se préoccuper de la qualité de l'air intérieur, car ils passent plus de 90% de leur temps à l'intérieur. Bien que le radon domiciliaire (RD) cause plus de décès que tout autre risques environnemental, 55% des Canadiens en ont déjà entendu parler, tandis que seulement 6% ont pris des mesures concrètes pour l'éradiquer. L'écart entre la sensibilisation aux risques et la prise de mesures de protection réelles par les résidents constitue un défi pour les professionnels de la santé publique. La perception des résidents face aux risques associés au RD devrait guider la communication en matière de santé pour cibler la motivation. Au Canada, très peu d'études portant sur les perceptions de la population face aux risques associés au RD ont été réalisées. **OBJECTIFS** : Décrire les perceptions qu'entretiennent **les occupants de bâtiments résidentiels** face aux risques pour la santé associée au RD et évaluer comment ces perceptions sont corrélées aux comportements de protection, notamment en appliquant la théorie de la motivation et de la protection. **MÉTHODES :** Nous avons réalisé une enquête mixte en ligne et en personne (n = 557) auprès de propriétaires et de locataires de la région d'Ottawa-Gatineau. Des analyses descriptives, corrélationnelles et des analyses de régressions ont été effectuées en fonction de nos questions de recherche. **RÉSULTATS** : En comparaison à la gravité des risques, les perceptions du public demeurent faibles. Bien que 32% des résidents ont exprimé des préoccupations au sujet du danger que représente le radon pour la


**Commented [SK1]:** Writing the other way as suggested would exceed the word limit of 150; so, we were obliged to keep as it was.

**Commented [SK2]:** 'severity of the risk' is a variable used all over in the article, it cannot be changed to 'risk significance'

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santé, seulement 12% d'entre eux ont réalisé des tests à domicile et seulement 3% ont pris des actions concrètes pour réduire les risques. Les perceptions des résidents quant à la probabilité et à la gravité des risques du RD sur leur santé, l'influence sociale, les soins prodigués aux enfants, ainsi que le tabagisme à la maison étaient significativement corrélées avec leur intention de réaliser un test. Ces facteurs ont également prédit leurs comportements en lien avec l'utilisation du test et les actions entreprises pour diminuer les risques. **CONCLUSION** : Les programmes de communication sur les risques du RD sur la santé doivent tenir compte des aspects affectifs associés à la perception des risques, en plus de tenir compte du niveau de connaissances pour améliorer les comportements de protection. Une recherche de nature qualitative serait nécessaire pour explorer les raisons qui expliquent l'écart entre le taux d'utilisation des tests de détection et les actions concrètes pour diminuer les risques.

Mots-clés: Pollution de l'air; radon domiciliaire; perceptions du risque; Canada.

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**Radon, an Invisible Killer in Canadian Homes: Perceptions of Ottawa-Gatineau Residents**

## INTRODUCTION

Canadians have reason to care about indoor air quality as they spend over 90% of the time indoors.[1] Having the world's most abundant reserves of high-grade uranium ($U^{238}$), Canadian land emits higher levels of soil gas radon ($Rn^{222}$) than any other country.[2] In urban areas, people of lower income levels are most likely to rent poorly ventilated basements or houses that are in contact with the ground.[3] Airtight energy efficient homes have pressure gradients between the heated indoors and chilly outdoors, which create conditions for harmful gases in the soil to enter the house.[4] Inside such dwellings, the radioactive gas builds up during the long winter months when doors and windows remain closed. Radon further degrades by emitting alpha particles which upon inhalation prompt mutations of lungs' DNA leading to cancer.[5]

In Canada, about 7% of homes have radon gas above the federal reference level of 200Bq/$m^3$.[6] Contingent on the long winter, construction design, urban location, and radiological anomaly in the Gatineau Park, Ottawa-Gatineau residents face an elevated risk of exposure to radon. There is no threshold for the carcinogenic effect of radon, and most lung cancers occur from exposure to concentrations below this set level[7], and such exposures are reported to increase the incidence of lung cancer.[4] Annually, at least 3,200 Canadians die from radon-induced lung cancer, accounting for 16% of all (smokers, ex-smokers, and non-smokers) lung cancer deaths and making radon the leading cause of lung cancer deaths among non-smokers and the second highest among smokers.[8] Compared to the general population, children (increased breathing rate), women (passing prolonged time indoor), and men smokers (synergistic effect of radon) with lower socioeconomic status are disproportionately affected by exposure to

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radon.[9] Lung cancer risk from radon exposure is up to ten times higher among smokers compared to non-smokers due to a synergistic effect.[10] Children in households with less educated parents are more likely to expose to second-hand smoking.[11]

Due to the public perception of low risk, radon has the highest impact on the health of the population among all environmental pollutants.[12] Despite multiple efforts, the National Radon Program (NRP) lags behind the desired public uptake.[8] In 2015, at least 55% of all Canadian households indicated hearing about radon, but only 6% of them tested their homes for it.[8] The gap between risk awareness and actual testing rates presents a challenge to public health practitioners. So far, practitioners assumed that better-communicated information, enforced guidelines, and tax rebates would be among the best solutions for radon health risk (only 'the risk' hereafter) management.[13] However, studies in the USA,[14] the UK,[15] and Ireland[16] showed that taking regulatory actions, offering rebates, and even providing free test kits and services could not significantly improve the program uptake. Thus, the key question - how to motivate the target population individually and collectively - remains unanswered.[17] Even after informing (cognitive awareness) residents that their houses might have a high level of radon and it might pose a serious health threat, protective actions remained low.[18] Social science research has argued that the success of a population-level health promotion program is contingent upon the motivation of key decision makers at the household level.[19] We believe that residents' perception of the risk should inform health communication programs targeting motivation. In Canada, research about the public perception of radon health risk is lacking. Therefore, in this study, we employed theory-based tools to understand the determinants related to residents' perceptions of the risk. We sought to determine whether they were motivated to change their behaviour due to cognitive awareness alone, or was there an effect of emotional influence related to the limbic part

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of the brain controlling affective behaviours[19]. Such understanding can guide strategies to enhance uptake of the program. This article reports the quantitative findings of a mixed methods study conducted in winter 2018.

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## THEORETICAL FRAMEWORK

Exposure to a health risk communication creates a dual appraisal process: a) threat appraisal and b) coping appraisal.[20] Threat appraisal is the assessment of the chance (susceptibility) of contracting a disease and evaluating its seriousness (severity). A coping appraisal comprises response efficacy and self-efficacy. Response efficacy is the expectation that carrying out recommendations will eliminate the threat. Self-efficacy denotes the belief in an individual's ability to accomplish suggested actions without failure.[20] Thus, the stronger a threat appraisal, the more an individual engages with the coping behaviour.

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The Protection Motivation Theory (PMT) specifies how these two perception processes lead an individual to either adopt an active adaptive or maladaptive coping mechanism in response to a health risk.[21] These, in turn, fortified by observational learning (someone died from radon-induced lung cancer), internal persuasions (lifestyle, smoking), intrapersonal traits (caring for family') and external environment ('social influence') leading to fear arousal and developing the intention to take action. These dual perceptions combined with multiple influences generate a broader perception ('worldview') about the risk that shapes the protection motivation and ultimately leads an individual to the actual adoption of coping behaviours.[22] Alternatively, the maladaptive responses place people at additional risk as they miss the opportunity to take preventive actions. Therefore, the PMT has four dynamics: a) perceived probability (exposure to radon); b) perceived severity of a threatening event (lung cancer); c) response efficacy of the recommended intervention (testing and mitigation can eliminate the threat), and d) self-efficacy

(confidently taking action). Thus, protection motivation is the result of informed threat and coping appraisal, which facilitates the adoption of protective health behaviours[22] (Figure 1).

Appraising homeowners' perceptions within the above fundamental logics of PMT might help to enhance understanding of the motivation dynamics, and identify strategies to influence protection behaviours. Therefore, this study examined the PMT components in a Canadian context to provide insight into homeowners' perceptions of radon health risk. The PMT has been previously applied in health research to influence and predict various health-related behaviours related to reducing alcohol consumption, enhancing healthy lifestyles, improving diagnostic health behaviours, and preventing diseases.[22] A thorough understanding of homeowners' perception of the risk through this theoretical lens can advance the PMT research agenda to promote awareness of health risks and encourage innovative approaches by policymakers and professionals to address the issue.

**RESEARCH QUESTIONS AND HYPOTHESIS**

The primary research question was: How do Ottawa-Gatineau residents perceive and act in response to the health risk of radon? In addition to inquiring about the risk perception phenomena and related worldviews, we sought to answer the following sub-questions:

i) What are the associations of residents' intention to test for radon, with the following variables: Perceived radon health risk susceptibility, severity, synergistic risk of radon with smoking, smoking in home, care for children and social influence?

ii) How do these variables (mentioned in 'i') predict residents' efficacy in adopting protection behaviours (testing and mitigation of homes for radon)?

We hypothesized that there would be significant associations between perceived radon health risk susceptibility, severity, synergistic risk perception, smoking in home, care for

children, social influence, with residents' intention to test for radon. Likewise, these variables will predict residents' adoption of protective behaviours.

## METHODS

**Sampling and Data Collection Protocol**. We surveyed homeowners and tenants (included for the first time in such a study as a control group) of Ottawa and Gatineau CMA who met the following criteria: Resident in a house with a basement or a house in contact with the ground for over one year. Participants were randomly selected from the residents' panel with Qualtrics, a platform frequently used in standard research studies.[23, 24] Participants received email invitations, along with a link to the online survey in both French and English. We conducted an equivalent, face-to-face version of the survey using iPads. Some participants filled out the survey and returned it by email, and others completed the face-to-face version in the community settings to cover up respondents who could not take the interview online. The University of Ottawa's Institutional Review Board approved the study and data collection protocols (file number: H10-17-03). Participation was voluntary and anonymous. All participants went through the informed consent form and checked option in affirmative to be able to go ahead with the survey. We estimated the sample size to be 560.

**Instrument and Measures**. The 41- item survey instrument included a mix of closed and open-ended questions. We measured the independent variables such as residents' 'perception of probability' (do you think radon may present in your home?) and 'perception of severity' (how seriously does radon affect our health?) of the risk across homeowners and tenants. We also measured internal factors such as 'smoking in home' (does anybody smokes cigarette in your home?) and 'synergistic risk perception' (does smoking enhance the risk of radon for lung cancer?). The intrapersonal factor included 'care for children' (does at least one child live or

spend over four hours in the basement or ground floor?) and external persuasion like 'social influence' (how many people you know who have tested their homes for radon?). Although the last three variables were measured in previous research in different settings,[25, 26] our pilot qualitative study conducted in winter 2017, helped to shape the questionnaire in a Canadian context. We employed an anchored relative scale rather than Likert scales as previous research has identified the former more sensitive than the latter.[27] The anchored relative scale quantified grading points with specific narratives rather than the inexplicit ranges. The open-ended questions explored residents' depth of knowledge and point of views regarding various aspects of radon health risk. The outcome (dependent) variables included 'intention to test' (have you the intention to test your home for radon?); 'tested home for radon' (have you ever tested your home for radon?); and 'mitigated home for radon' (did you fix or mitigate your home after testing?). The efficacy was enquired by asking about repeated action (did you test after mitigation?). The open-ended questions explored residents' general awareness (what do you know about radon?) and point of views regarding risk management (is it an individual or overall societal problem? Then, who should be responsible for fixing it?).

We collected sociodemographic (control) variables such as age, gender, race/ethnicity, education level, total household income and home ownership or tenancy to compare how the risk perceptions vary with these features. We followed the criteria used in the National Households and the Environment Survey[10] to classify gender, age group, race/ethnicity, education and income groups. Participants voluntarily identified themselves and chose their groups. We conducted a reliability analysis of our perception scales (susceptibility and severity of the risk) and obtained an internal consistency score of .74 (Cronbach's alpha) with a 2-item adapted scale.

**ANALYSIS**

The missing data in our sample missed at random and incomplete responses (completing <80% of the survey) accounted for less than 10% of the total sample - we excluded these data from further analysis. Because our focus was on Ottawa-Gatineau residents, we eliminated all participants who completed the survey from outside this area. With an overall 45% response rate, our final sample (N=557) had 394 (71%) homeowners and 163 (29%) tenants.

We conducted descriptive and inferential analyses using IBM SPSS 24, setting the confidence intervals at 95% and alpha at 0.05 (two-tailed) overall. Descriptive statistics included frequency distributions to summarize the data. We conducted univariate analyses for the entire sample, subgroups (homeowners and tenants), and outcomes variables. Initially, we did post hoc analyses to test the sensitivity of the methods used. We used Pearson's Chi-square test of associations and likelihood ratios to determine whether the risk related perception variables were associated with residents' intention and actual performance of protection behaviours (testing and mitigating). We arranged the data to meet all relevant assumptions related to multicollinearity, outliers, normality, homoscedasticity, and independence of residuals.[28] We conducted ordinal and binary logistic regressions to identify predictors of *intention to test* and actual *testing* and *mitigating* behaviours (both dichotomized into 'yes' and 'no'). We examined the fit of our proposed model, controlled for age, gender, race/ethnicity, education, total household income, and home ownership. In the regression analysis, variables were entered simultaneously and forward conditional method in each of the models.

## RESULTS

**Sample Characteristics:** Our sample proportionately represented sociodemographic features of Ottawa-Gatineau CMA residents.

"<Table 1 here>"

Table 1 presents these characteristics and their associations with residents' intention to test their homes for radon. We found significant associations (p=<.001) of residents' homeownership, gender and age groups with their intention to test for radon. However, homeowners, females and older adults had greater intention to test than tenants, males, and young adults. Although European Canadians, university educated and lower-middle-income residents showed a higher level of intention to test their houses for radon, these associations were not statistically significant. However, when it comes to taking actual protective actions, males and young adults exceeded their counterparts in testing. Though, the university educated and the upper-middle-income group of people took the lead in mitigating their homes for radon.

"<Table 2 here>".

Regarding indoor air quality, more people expressed concern about dust/dust mites (29%) and mold (27%) than radon (20%). Among the residents concerned about radon, 39% described it as a radioactive gas. Their primary sources of information were media (46%), Health Canada (13%) and internet browsing 8.5%.

"<Figure 2 here>"

Figure 2 shows that overall only 32% of residents had the concern about exposure to radon health risk, 12% tested for radon, and just 3% mitigated their homes for the risk. Among those who mitigated, 94% re-tested after mitigation (p=<.001) showing the efficacy of adopting protection behaviours. Although 3% of tenants also tested, none of them mitigated their houses for radon. Our analysis showed that 93% of homeowners and 85% of tenants spent more than four hours either in the basement or on the ground floor. This variable had a significant correlation with testing for homeowners (p=.01) but not for tenants (p=.904). Both smoking in home and synergistic risk perception were significantly associated with the intention to test by

homeowners ($X^2$=107.12, 172.42; p=<.001, <.001) and tenants ($X^2$=42.17, 88.22; p=<.001, <.001). 21.8% of homeowners and 5% of tenants had at least one children living in the basement or on the ground floor that had strong associations with the intention to test for both homeowners' ($X^2$=81.82, p=<.001) and tenant's ($X^2$=13.08, p=<.001). Similar strong associations were found between social influence and intention to test for both homeowners ($X^2$=41.66; p=<.001) and tenants ($X^2$=4.54, p=.03).

When asked about their worldview about radon, the majority (28%) of respondents said that they are concerned about the health since radon exposure affects everybody. Over 26% said that radon affects individual persons, so they (homeowners) are responsible for fixing it. About 25% said that property owners and tenants should get a tax rebate according to their income level for mitigating their homes. Nearly 21% said that as this is a population health problem, so the government is responsible for fixing it. These opinions did vary significantly by residents' gender ($X^2$=35.20, p=<.001), age ($X^2$=29.24, p=<.01), education ($X^2$=32.36, p=<.001) and income levels ($X^2$=27.49, p=<.02) but not with homeownership and race/ethnicity.

**Results to Answer the Research Questions:** We assumed that there would be significant associations between perceived radon health risk susceptibility, severity, synergistic risk perception, smoking in home, care for children, social influence, with residents' intention to test for radon. Likewise, these variables will predict residents' adoption of protection behaviours that are to take actual actions such as testing and mitigation of homes for radon.

"<Table 3 here>"

Table 3 presents the outcomes of ordinal and binary logistic regressions that show the perception variables were significantly associated with residents' intention to test for radon as well as predicted residents' efficacy in actually adopting the protection behaviours.

## DISCUSSION

Our purpose in this study was to describe residents' perceptions of radon health risks and to evaluate how perceptions correlated with protection behaviours applying the protection motivation theoretical lens. We examined the perception of radon health risk of an illustrative sample of Ottawa-Gatineau residents. In doing so, we compared the obtained measures on the perception variables of interest with residents' sociodemographic features and identified mixed associations with their intention to test and actual protection behaviours. Our analyses showed significant associations of perception variables with residents' intention to test for radon. The same variables meaningfully predicted residents' actual protection behaviours; thus, confirmed the hypotheses. These findings correspond with the results of studies conducted by Hahn at al.[29] in the USA and Butler et al.[25] in the UK.

A few quantitative studies in Canada have assessed the environmental health risk perceptions in general. Among these, Krewski et al.[30] conducted a national survey on health risk perception and looked into thirty common health hazards. A more focused study by Spiegel and Krewski[13] evaluated health risk perception of radon along with three other health hazards affecting residents of high radon areas in Winnipeg and Manitoba. They examined residents' compliance with the radon guideline and concluded that the Canadian Radon Guideline is not effectively prompting homeowners to reduce radon exposure.[13] Our findings support this conclusion that compared to the gravity of the risk, residents' perception level remains low. Although those studies credibly supported the federal government initiative to develop a guideline, no follow-up study purposefully focused on radon health risk perception to support the National Radon Program of Health Canada. This study successfully fills that scholarly gap in the literature.

**Commented [SK18]:** Authors of this paper considered the results of studies conducted by Hahn et al. and Butler et al. be discussed here to show that our findings corresponded with those of these two researchers. Moreover, we have already used the space and word limits for lit. review.

As stated before, we included tenants for the first time in a study and came up with astounding findings. Although a few (3%) in number, tenants also tested their houses for radon due to having concern for their children living in the basement. However, none of them mitigated their homes. An apparent reason for this is the lack of authority to do so; nonetheless, there exists no law that gives tenants the right to hold homeowners responsible for such mitigation. Homeowners who mitigated their houses similarly happened to have children sleeping in the basement. Besides, they observed other to do so or heard of people who had radon-induced lung cancer. Application of these perception points may, however, create fears and apprehensions among tenants and occupants of public buildings who, for the time being, are not required to measure and mitigate radon. These can also dissipate the ambiguity in the program on radon health communication and help to deliver the health communication messages to the right audience in the right manner; thus, can open up a new path for the public health preventive interventions.

**Commented [SK19]:** Re-organized the phrase and clarified as recommended

**Commented [SK20]:** Added the words as advised

Again, the significant correlation between having children live in the basement or on the ground floor and taking actual protective behaviours might have biological plausibility. Here, the targeted health communication message that can stir the affection part relating to the inner cortex or limbic brain would yield a better outcome compared to those emphasizing only the rational cognitive part pertaining to the neocortex. These findings warrant further exploration of social influence through an in-depth qualitative study to test whether motivation works under the affective familial or social influence that can open the way to make protection behaviours a norm in the society.

Although our study targeted one metropolitan area, this CMA spreads over two provinces in the capital region and covers both English and French-speaking population; thus, filled a

critical gap in measuring residents' perception of radon health risk across two official linguistic groups in Canada. Thereby, a systematic understanding of homeowners' perceptions through the Protection Motivation theoretical lens advances the PMT research agenda and puts forward evidence for innovative approaches to be considered by policymakers and professionals in addressing the critical public health issue of radon.

## LIMITATIONS

Our study is limited in demographic scope. We may have overlooked demographic diversities and cultural subtleties in selecting the sample online that could have skewed our results. Our sample did include tenants, but the lack of variability in the scores may have affected the relationship between them. Furthermore, residents who took the survey did so voluntarily who have access to the internet; therefore, we collected proportional responses offline using iPad to include the rest 10% of residents having no access to the internet. Our study included only residents in Ottawa-Gatineau and should be understood in the context of this population. Though the sample was in proportion to the demographic features of the Canadian population, we cannot claim it to be representative of the whole Canadian demography. A future study with a national representative sample will have stronger evidence.

## CONCLUSION

In this study, we tested the hypothesis that those with the higher levels of perceived susceptibility, severity, synergistic risk perception, smoking in home, care for children and social influence would be more likely to have the intention to test as well as to demonstrate protection behaviours regarding testing and mitigating their homes. The statistical analyses of survey data confirmed this hypothesis in an ideal Canadian context. The perception variables did not always convert into the protection behaviours that could be explained by biological plausibility. Finally,

through the protection motivation theoretical lens, we have now understood that residents' perceptions of the risk of radon are a reliable marker of intention to test their house for radon as well as a clear predictor of actual protection behaviours.

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**Figure 1: Theoretical Lens: Protection Motivation Theory**

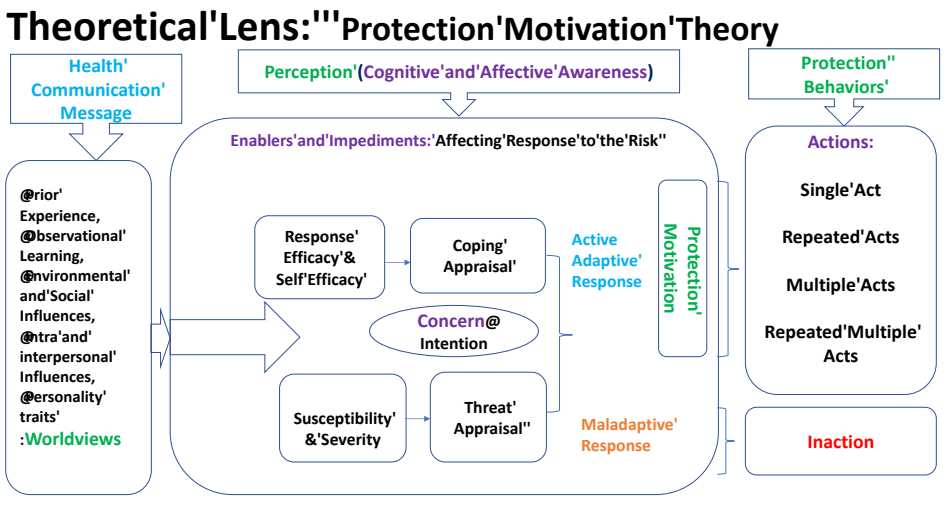


Figure 1: Developed with ideas from the Protection Motivation Theory of Rogers (1983)[21,22]

**Table 1: Associations of sociodemographic characteristics with residents' intention to test homes for radon**

| | Residents' Intention to Test Homes for Radon | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sociodemographic Characteristics** | Total Sample (N=557) | | Yes | | No | | Associations (Significance) |
| | N | % | N | % | N | % | $X^2$ (p)‡ |
| **Homeownership** | | | | | | | |
| Owners | 394 | 71 | **179** | **80** | 215 | 65 | 14.18* (.000§) |
| Tenants | 163 | 29 | 46 | 20 | 117 | 35 | |
| Gender | | | | | | | |
| Male | 291 | 52 | 88 | 39 | 203 | 61 | 29.82* (.000§) |
| Female | 224 | 40 | **121** | **54** | 103 | 31 | |
| No willing to identify | 42 | 8 | 16 | 7 | 26 | 8 | |
| **Age groups** | | | | | | | |
| 18-24 year | 83 | 15 | 46 | 20 | 37 | 11 | |
| 25-34 year | 58 | 10 | 35 | 16 | 23 | 7 | |
| 35-44 year | 59 | 11 | 33 | 15 | 26 | 8 | 85.76* (.000§) |
| 45-54 year | 85 | 15 | 50 | 22 | 35 | 11 | |
| 55-64 year | 106 | 19 | 9 | 4 | 97 | 29 | |
| 65 and above | 166 | 30 | **52** | **23** | 114 | 34 | |
| **Race/Ethnicity** | | | | | | | |
| European Canadian | 375 | 67 | **146** | **65** | 229 | 69 | |
| First Nations | 14 | 2.5 | 5 | 2 | 9 | 3 | 1.95* (.583) |
| Visible Minorities | 120 | 21 | 55 | 24 | 65 | 20 | |
| Prefer not to answer | 48 | 9 | 19 | 8 | 29 | 9 | |
| **Education** | | | | | | | |
| High School or less | 70 | 13 | 25 | 11 | 45 | 14 | |
| College | 135 | 24 | 54 | 24 | 81 | 24 | 7.32† (.062) |
| University | 346 | 62 | **146** | **65** | 200 | 60 | |
| Prefer not to answer | 6 | 1 | 0 | 0 | 6 | 2 | |
| **Income groups** | | | | | | | |
| Lowest subsistence | 60 | 11 | 28 | 12 | 32 | 10 | |
| Lower middle, non-skilled | 147 | 26 | **60** | **27** | 87 | 26 | |
| Skilled working class | 94 | 17 | 36 | 16 | 58 | 17 | 2.09* (.836) |
| Middle class | 106 | 19 | 44 | 20 | 62 | 19 | |
| Upper middle | 68 | 12 | 28 | 12 | 40 | 12 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Prefer not to answer | 82 | 15 | 29 | 13 | 53 | 16 | |

**Pearson Chi-Square ($x^2$); †Likelihood ratio; ‡Asymptotic significance (2 sided); §Significant association*

**Figure 2: Residents' concern about radon health risk; actual testing and mitigation behaviours**

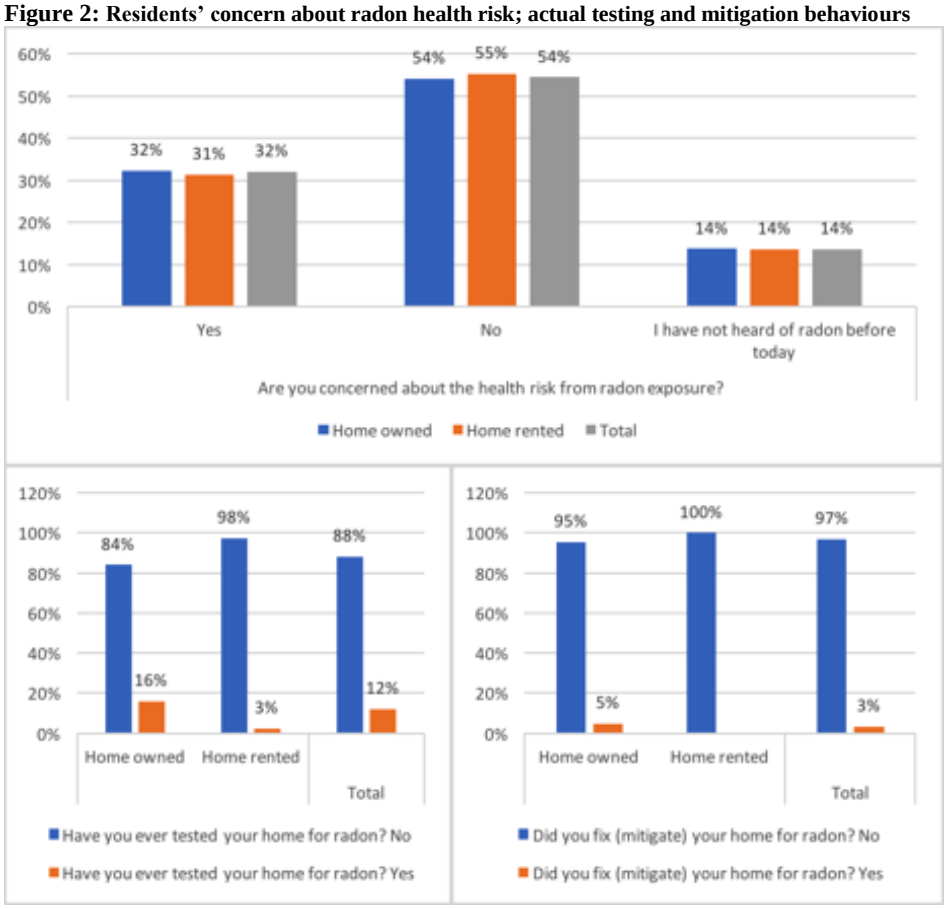


**Table 2: Associations of sociodemographic characteristics with residents' actual testing and mitigation of homes for radon**

| | Residents Ever Tested Homes for Radon | | | | | | | Mitigated homes for radon | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sociodemographic Characteristics** | **Total Sample (N=557)** | | **Yes** | | **No** | | **Associations (Significance)** | **Total Sample (N=557)** | | **Yes** | | **No** | | **Associations (Significance)** |
| | **N** | **%** | **N** | **%** | **N** | **%** | **$X^2$ (p‡)** | **N** | **%** | **N** | **%** | **N** | **%** | **$X^2$ (p‡)** |
| **Homeownership** | | | | | | | | | | | | | | |
| Owners | 394 | 71 | 63 | 94 | 331 | 68 | | 394 | 71 | **17** | **100** | 377 | 70 | 7.69* |
| Tenants | 163 | 29 | 4 | 6 | 159 | 32 | 19.96* (.000§) | 163 | 29 | 0 | 0 | 163 | 30 | (.006§) |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gender** | | | | | | | | | | | | | | |
| Male | 291 | 52 | **34** | **51** | 257 | 52 | | 291 | 52 | **10** | **56** | 281 | 52 | |
| Female | 224 | 40 | 31 | 46 | 193 | 40 | 2.82* (.244) | 224 | 40 | 8 | 44 | 216 | 40 | 1.52* |
| No willing to identify | 42 | 8 | 2 | 3 | 40 | 8 | | 42 | 8 | 0 | 0 | 42 | 8 | (.467) |
| **Age groups** | | | | | | | | | | | | | | |
| 18-24 year | 83 | 15 | **19** | **28** | 64 | 13 | | 83 | 15 | **6** | **35** | 77 | 14 | |
| 25-34 year | 58 | 10 | 11 | 16 | 47 | 10 | | 58 | 10 | 3 | 18 | 55 | 10 | |
| 35-44 year | 59 | 11 | 10 | 15 | 49 | 10 | 18.59† (.000§) | 59 | 11 | 5 | 29 | 54 | 10 | 17.43† |
| 45-54 year | 85 | 15 | 9 | 13 | 76 | 15 | | 85 | 15 | 2 | 12 | 83 | 15 | (.004§) |
| 55-64 year | 106 | 19 | 5 | 8 | 101 | 21 | | 106 | 19 | 0 | 0 | 106 | 20 | |
| 65 and above | 166 | 30 | 13 | 19 | 153 | 31 | | 166 | 30 | 2 | **6** | 164 | 31 | |
| **Race/Ethnicity** | | | | | | | | | | | | | | |
| European Canadian | 375 | 67 | **36** | **54** | 339 | 69 | | 375 | 67 | **10** | **56** | 365 | 68 | 2.48† |
| First Nations | 14 | 3 | 2 | 3 | 12 | 3 | 6.65* (.08) | 14 | 3 | 0 | 0 | 14 | 3 | (.479) |
| Visible Minorities | 120 | 21 | 20 | 30 | 100 | 20 | | 120 | 21 | 6 | 33 | 114 | 21 | |
| Prefer not to answer | 48 | 9 | 9 | 3 | 39 | 8 | | 48 | 9 | 2 | 11 | 46 | 8 | |
| **Education** | | | | | | | | | | | | | | |
| High School or less | 70 | 13 | 7 | 10 | 63 | 13 | | 70 | 13 | 1 | 6 | 69 | 13 | |
| College | 135 | 24 | 17 | 25 | 118 | 24 | .439* (.932) | 135 | 24 | 4 | 22 | 131 | 24 | 1.63† |
| University | 346 | 62 | **42** | **63** | 304 | 62 | | 346 | 62 | **13** | **72** | 333 | 62 | (.652) |
| Prefer not to answer | 6 | 1 | 1 | 1 | 5 | 1 | | 6 | 1 | 0 | 0 | 6 | 1 | |
| **Income groups** | | | | | | | | | | | | | | |
| Lowest subsistence | 60 | 11 | 11 | 16 | 49 | 10 | | 60 | 11 | 3 | 18 | 57 | 11 | |
| Lower middle, non-skilled | 147 | 26 | **19** | **28** | 128 | 26 | 5.73* (.333) | **147** | **26** | 4 | 23 | 143 | 26 | 5.24† |
| Skilled working class | 94 | 17 | 10 | 15 | 84 | 17 | | 94 | 17 | 1 | 6 | 93 | 17 | (.387) |
| Middle class | 106 | 19 | 9 | 13 | 97 | 20 | | 106 | 19 | 3 | 18 | 103 | 19 | |
| Upper middle | 68 | 12 | 12 | 18 | 56 | 12 | | 68 | 12 | **5** | **29** | 63 | 12 | |
| Prefer not to answer | 82 | 15 | 7 | 10 | 75 | 15 | | 82 | 15 | 1 | 6 | 81 | 15 | |

*Pearson Chi-Square ($x^2$); †Likelihood ratio; ‡Asymptotic significance (2 sided); §Significant association*

**Table 3: Ordinal and binary regression modeling: Residents' perception of radon health risk predicting their intention to test; actual testing and mitigating homes for radon**

| Variables | Intention to test | | | | Tested home for radon | | | | Mitigated home for radon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate/ β | SE | Wald/ Std. β | p | Estimate/ β | SE | Wald/ Std. β | p | Estimate/ β | SE | Wald/ Std. β | P |
| **Perceived susceptibility of radon risk*** | 2.09 | .65 | 10.32 | .001§ | 18.83 | .36 | 2762.37 | .000§ | 18.55 | .66 | 787.52 | .000§ |
| **Perceived severity of radon risk†** | 2.56 | .42 | 36.85 | .000§ | 2.46 | .62 | 15.56 | .000§ | 20.31 | .66 | 936.99 | .000§ |
| **Synergistic risk perception‡** | -3.68 | .37 | 97.79 | .000§ | -3.4 | .41 | 67.91 | .000§ | -2.53 | .64 | 15.7 | .000§ |
| **Smoke in home‡** | -2.08 | .35 | 35.73 | .000§ | -3.57 | .39 | 81.7 | .000§ | -4.02 | 1.03 | 15.12 | .000§ |
| **Care for children‡** | -2.07 | .49 | 17.75 | .000§ | -5.45 | .55 | 98.97 | .000§ | -4.62 | 1.04 | 19.92 | .000§ |
| **Social influence‡** | 2.32 | .60 | 14.73 | .000§ | -6.5 | .60 | 118.84 | .000§ | -4.97 | 1.04 | 22.89 | .000§ |

**Ordinal regression model fit statistics for intention to test are Likelihood = 21.47, p < 0.001, and $X^2$ = 100.43, df=4.*
*†Ordinal regression model fit statistics for intention to test are Likelihood = 20.09, p < 0.001, and $X^2$ = 75.04, df=3.*
*‡Binary regression model, Hosmer and Lemeshow test's $X^2$ =47.42, p<0.001, df=4.*
*§Values refer to the predictors that are significant in the model. SE=standard error of β; Std. β=standardized beta, $X^2$= Chi-Square statistic, df=degree of freedom.*

Commented [SK21]: