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Preventing Lyme disease through identification of key beliefs

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Abstract

Lyme disease and other vector-borne diseases are on the rise because of climate change. In the province of Quebec, Canada, Lyme disease has become a public health problem deserving the attention of health authorities. Despite their recognized effectiveness at preventing tick-to-human transmission, rates of adoption of Lyme disease adaptive behaviours (LDAB) remain relatively low in the population. Using the Theory of Planned Behaviour (TPB), the aim of this study is to identify specific and actionable beliefs associated with the adoption of Lyme disease adaptive behaviours. Specifically, 2,011 people were surveyed to determine the decision-making process behind specific beliefs, which could be targeted for raising awareness. Statistically significant associations were found between the three determinants of the TPB (i.e., attitudes, perceived social pressure and perceived behavioral control) and the intention to adapt. In addition, the intention itself was significantly associated with adopting LDAB. Belief-based analyses indicated that 8 primary beliefs (4 behavioral beliefs, 2 normative beliefs, and 2 control beliefs) were associated with LDAB. Among these, control beliefs (barriers and facilitating factors) appeared to have the greatest impact on adaptation. These findings can be used to guide educational and awareness-raising campaigns to promote LDAB by changing or reinforcing these primary beliefs.

Introduction

Among the myriad risks to human health and wellbeing exacerbated by climate change [1–5] is an increase in vector-borne diseases [6–10]. In North America, *Ixodes scapularis*, a vector of Lyme disease's causative agent, *Borrelia burgdorferi*, has spread northward from the United

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States into Canada due to climate and environmental changes [9, 11–15]. As a result, the number of Lyme disease cases reported in the Canadian population has increased, from 144 cases in 2009 to 2,634 cases in 2019 [16, 17]. Evidence suggests that in North America, the numbers, types, activity levels, and geographical distribution of *I. scapularis* are increasing due to the rising temperatures associated with climate change [18–20]. The magnitude of the impact of climate change on Lyme disease risk is likely to vary regionally [9, 21]. Despite evidence of the increasing emergence and spread of Lyme disease, some studies show that relatively few Canadians understand the impacts of climate change on health and the expansion of zoonotic diseases [22–24].

The first human case of Lyme disease in the province of Quebec was identified in 2008 [15, 25, 26]. The number of cases since then has markedly increased and is actively monitored by the Quebec Ministry of Health and Social Services [27, 28]. The number of reported cases originating from within the province increased from five cases in 2011 to 650 cases in 2021 [29]. This increase can be partly explained by variations in temperature, rain, and humidity, which can have a direct impact on the reproduction rates and development of ticks, their biting activity, the density of their populations and their search for hosts [15, 19, 30–32]. The abundance and diversity of host species (e.g., deer, migratory birds, small rodents, and chipmunks) may also favor tick survival, as well as the increased suitability of habitats for ticks due to warmer winters associated with climate change [18, 33, 34].

Lyme disease is caused by the *Borrelia burgdorferi* sensu lato (s.l.) complex of spirochete bacteria, which is transmitted to humans during a bite from an infected tick. The first and most common symptom of Lyme disease is a red skin rash known as erythema migrans, which is present at the site of the tick bite in 70% to 80% of cases [35]. Other symptoms include fever, fatigue, headache, stiff neck, and muscle and joint pain. In the absence of early treatment, the disease can cause chronic multisystem morbidity including cardiac or neurological issues and arthritic joint deterioration [35, 36]. With no available vaccine for Lyme disease, behaviours aimed at reducing skin exposure to ticks or detecting and removing ticks during a tick bite remain the most effective Lyme disease prevention strategies. These Lyme disease adaptation behaviours (LDAB) include wearing long, light-coloured clothes that cover the skin, applying insect repellent, and thoroughly checking one's skin and clothes for ticks when returning from the outdoors, among others [37–44].

Previous studies examining LDAB have focused mainly on evaluating their overall levels of adoption and understanding the relationships between adaptation and various psychosocial variables. These include perceived risk of contracting the disease, knowledge about the disease [44–47] and its mental and physical impacts [48], as well as attitudes and barriers to adaptive behaviour [49]. Others also explore the perceived efficacy of protective behaviours against the disease, perceived control over Lyme disease prevention measures [50, 51], and the acceptability and effectiveness of Lyme disease prevention programs [52, 53]. Past research has also evaluated the determinants of intention to adopt LDAB using psychosocial models such as the Attitude-Social-Influence-Efficacy (ASE) model [54] and the Theory of Planned Behaviour (TPB) [55, 56]. Indeed, Omodior et al. [55] and Valois et al. [56] found that the constructs of the TPB (attitudes, social norms, and perceived behavioural control) were effective predictors of intention to engage in LDAB. Complementary to these previous results, the current research seeks to uncover key beliefs underlying these precursors of intention, which represents a gap in the literature on LDAB. As a well-established social-cognitive model, the TPB is an excellent tool to identify beliefs that can be addressed in public health messages aiming to limit Lyme disease by promoting adoption of LDAB [57].

People's beliefs are influenced by multiple factors, including their own experiences, formal education, media, and interactions with family and friends [58]. Once a population's primary beliefs regarding adoption of LDAB have been identified, health and communication professionals can use that information to design interventions to increase the population's intentions to adopt LDAB and to help them act on their intentions [59].

Theory of Planned Behaviour

Since its publication in 1985, the TPB has been extensively used to predict and explain human social behaviour in various domains [59, 60] including health behaviours [57], adaptation behaviours [61–63], and pro-environmental behaviours [64, 65]. The TPB is therefore a well-established theory, with TPB-based behavior change interventions rapidly growing and expanding to numerous domains [59]. Its versatility in predicting intentions and behaviors has also been synthesized in several meta-analyses [66–68].

A variety of other theories are available to assess health and adaptation behaviors, such as the health beliefs model (HBM) [69]), the protection motivation theory (PMT) [70], the model of private proactive adaptation to climate change [71], or the Value-Belief-Norm model [72]. The TPB, however, offers a unique advantage by combining the main variables discussed in other models into a single theoretical framework [73]. For instance, the notions of efficacy and control included in the definition of adaptation beliefs, a variable proposed by Grothmann et al. [74] are well represented by the behavioral and control beliefs of the TPB. Similarly, the behavioral evaluation construct found in the HBM, which integrates beliefs about the advantages and the effectiveness of a behavior are reflected in the behavioral beliefs of the TPB. In addition, according to Fishbein & Ajzen [59], it is possible to add other predictors to the TPB. The perception of risk, for example, an important construct of the PMT (threat assessment) and the HBM (perception of the threat) has been included successfully as a construct of the TPB in other studies [75]. These characteristics have motivated us to retain the TPB as our theoretical framework.

Consistent with the concept of reasoned action, which is the basis of the TPB, people's behavioural intentions towards preventing tick bites and Lyme disease are presumed to be guided by some measure of deliberation [76]. Using the TPB as a guide, the intention to adopt preventive behaviours against tick bites and Lyme disease precedes the adoption of LDAB (Fig 1). Similarly, this intention is preceded by three factors: attitudes, social norms, and perceived behavioural control. Attitudes relate to the positive or negative values a person has towards the adoption of LDAB, social norms correspond to the social pressure a person perceives in engaging or not in LDAB, and perceived behavioral control refers to a person's perception of their own capacity to perform LDAB [77]. In addition, an individual's perception of control, to the extent that it faithfully reflects actual control, can moderate the effect of intentions on behavior [78]. In Fig 1, this moderating effect is illustrated by the dotted arrow.

According to the TPB, people's intention to adopt preventive behaviours against tick bites and Lyme disease should therefore be high if: (a) they have favourable attitudes toward adaptive behaviours (i.e., they positively value the adoption of LDAB); (b) they believe that significant others (e.g., relatives, physicians) have expectations about or support LDAB; and (c) they believe they have the ability to perform LDAB (i.e., believe they can overcome any obstacles to carrying out their intentions, and/or recognize facilitating factors such as prior experience with Lyme disease or support from friends to overcome obstacles).

In addition, the TPB states that attitudes, perceived social norms, and perceived behavioral control are based on three kinds of beliefs: behavioral beliefs (i.e., beliefs about the potential benefits and risks of adopting a particular behaviour), normative beliefs (i.e., beliefs about the extent to which their important referents (e.g. friends, physicians, etc.) approve of them protecting themselves from Lyme disease), and control beliefs (i.e., their perception of the

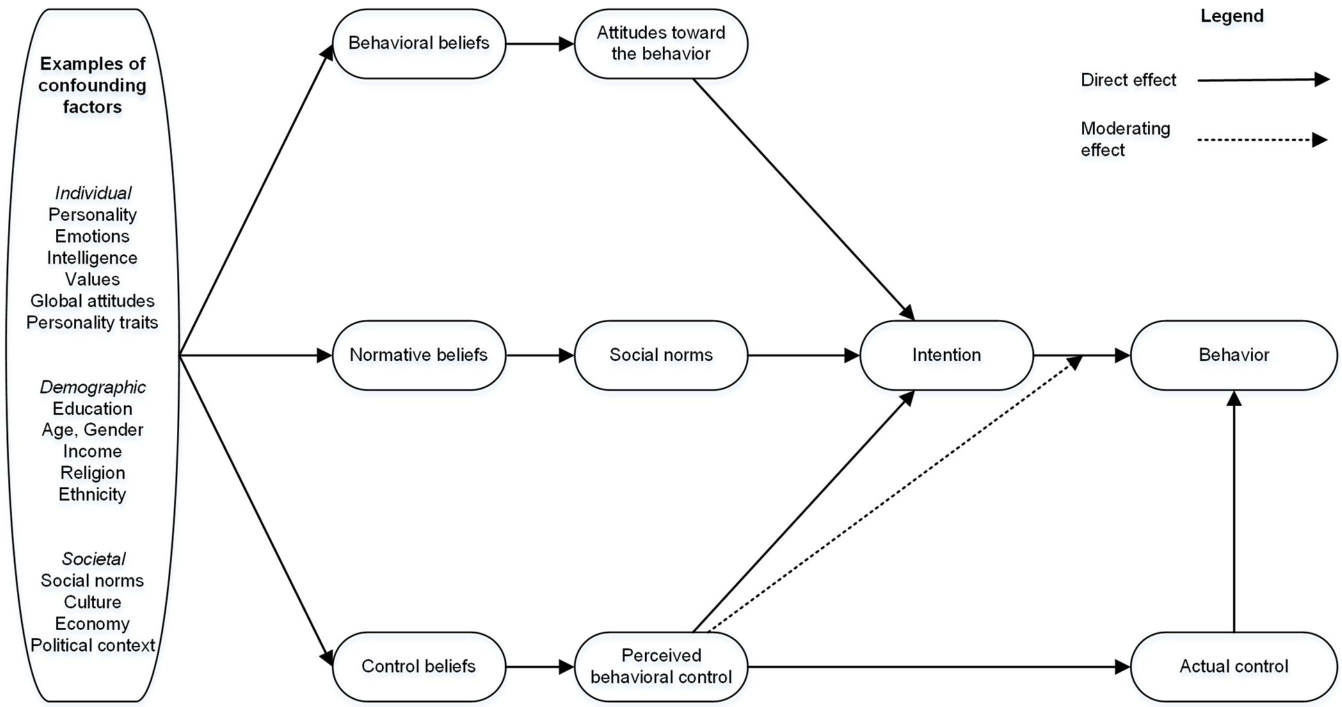

Fig 1. Theory of Planned Behaviour. Adapted from Ajzen and Cote [79].

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presence of factors that facilitate or hinder their adoption of LDAB) (Fig 1). These beliefs underlie the formation of attitudes, perceived social norms, and perceived behavioral control. Understanding these specific beliefs leads to a more comprehensive understanding of the full psychosocial process that leads to the adoption of health behaviours aimed at preventing Lyme disease, an essential step toward designing effective health communication and interventions [59].

Objectives

This study is part of a larger research project aiming to monitor and evaluate individuals' adaptation to Lyme disease. In this context, the purpose of the current study was twofold: 1) to apply the TPB in predicting LDAB adoption in the population of Quebec, Canada; and 2) to identify the primary beliefs influencing the adoption of LDAB based on the results of the first objective.

Materials and methods

Ethics statement

This study was approved by Université Laval Human Research Ethics Committee (Ref. #109526). Before completing the survey, participants were explicitly asked for their informed consent.

Pilot study

Before conducting a TPB-based study, Ajzen [60] recommends performing a pilot study to determine the salient beliefs associated with a specific behaviour in a given population. It is crucial to conduct this preliminary study to avoid researchers making an arbitrary selection of these beliefs [60]. Thus, five focus groups of 4–5 persons (n = 21) recruited by the polling firm

Léger were conducted in early 2021. Beliefs about LDAB were determined through an open-ended questionnaire. Specifically, participants were asked to discuss: (a) the benefits and disadvantages they would experience by adopting LDAB over the next year; (b) which people or groups of people would approve or disapprove of their adoption of LDAB in the next year; and (c) which factors might facilitate or impede their adoption of these behaviours in the next year. Quantitative measures of behavioral, normative, and control beliefs were subsequently elaborated and included in the survey questionnaire using the more frequently cited outcomes, referents, and control factors reported during the focus groups.

Lastly, to assess the psychometric qualities of the TPB constructs, a pretest of the final survey was conducted with a subsample of 56 participants prior to data collection for the main study. According to item analyses based on the item response theory approach [80], the scales used in the pretest were adequate.

Main study

Participants. The target population for this study was individuals aged 18 and up living in the following 12 administrative regions of the Canadian province of Quebec (1,667,441 km^2; population 8.7 million): Chaudière-Appalaches, Capitale-Nationale, Centre-du-Québec, Estrie, Lanaudière, Laurentides, Laval, Mauricie, Montérégie, Montréal, Outaouais, and Saguenay-Lac-Saint-Jean. These regions were specifically targeted because they comprise municipalities where the public is at risk of acquiring Lyme disease [27, 81]. The target sample size was 2,000 participants, with a quota of participants for each administrative region based on its proportion of the province's total population, then corrected using Kish's over-sampling method [82]. More information on the survey sample characteristics can be found in Table 1.

Table 1 shows that the proportion of men and women in our sample corresponds to that of the target population according to Statistics Canada census data [83]: $\chi^2 = 1.14$, n.s., nil effect size. However, the sociodemographic characteristics differ from the target population in age, income, and education. The respondents were generally more educated (large effect size) and had a higher household income (large effect size). The proportions of respondents aged between 65 to 74 and older than 75 years old are lower than the proportion in the target population (small effect size) [84, 85].

Data collection. The data collection, from the preliminary focus groups to the main survey dissemination, was managed by the survey firm Léger. Participants were selected from the company's pool of 225,000 panelists residing throughout the province of Quebec. To attain the desired regional quotas and sample size (2,000 participants), the survey firm sent invitations to a subset of 17,752 panelists. These were sent in waves rather than all at once to increase the likelihood of obtaining a more representative sample by soliciting responses throughout the data collection period. In total, 11 invitations waves were sent. First, invitations were sent to 8,945 people in 5 waves over 5 days (one by day). Second, 5,950 additional people were contacted over 4 days in 4 waves. Finally, 2,857 more people living in regions where quotas were not yet met were sent invitations in 2 waves. Before ending the data collection, a general reminder was sent to all those invited, but who had not yet accessed the survey, ensuring that each potential respondent had the same probability of being contacted during the survey period. The raw data (S1 Data) collected during the survey (and whose codes correspond with the questionnaire: S1 File) can be accessed in the supporting information. The survey was accessible to participants on any day of the week, at any time, from any Internet-enabled device (computer, tablet, smart phone, etc.). The median completion time for the survey was 19 minutes and 43 seconds. Léger's web panel point program, in which panelists can trade points earned by completing surveys for gift cards, was the main incentive for participation.

Table 1. Characteristics of the survey sample in relation to the target population.

	Study Sample		Targeted Population (%)	Chi square goodness of fit	Cramer's V
	Frequency	(%)			
Age					
18–34	525	26,11	27,76	102,90***	0,13 (Small)
35–44	331	16,46	15,98		
45–54	347	17,26	14,80		
55–64	360	17,90	17,30		
65–74	353	17,55	13,71		
75+	90	4,48	10,45		
Prefer not to answer	5	0,25			
Gender					
Men	961	47,79	49,02	1,14	0,01 (Nil)
Women	1049	52,16	50,98		
Other	1	0,05			
Income (yearly, CAD$)					
Under $20,000	158	7,86	21,50	1204,20***	0,34 (Large)
$20,000–$40,000	273	13,58	29,85		
$40,000–$60,000	323	16,06	22,12		
$60,000–$80,000	280	13,92	12,25		
$80,000–$100,000	295	14,67	6,59		
Above $100,000	440	21,88	7,65		
Don't know	242	12,03			
Education					
Primary school or less	34	1,69	18,03	452,11***	0,29 (Large)
High school (partial or complete)	342	17,01	21,57		
Postsecondary	920	45,75	36,33		
University	708	35,21	24,07		
Don't know/Prefer not to answer	7	0,35%			

* p-value <0.05

** p-value <0.01

*** p-value <0.001

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Questionnaire. The questionnaire consisted of close-ended questions, and included questions to assess behavioural adaptation, TPB constructs, as well as background variables such as age, gender, and annual net income (S1 File).

Lyme disease adaptation behaviours. To measure this construct, we used a previously validated index of Lyme disease prevention behaviours in Québec [56]. Respondents indicated how often they adopt each of the 10 behaviours in the index (see Table 2). The first question was a "Yes" (1) or "No" (0) question, while the remainder (questions 2 to 10) were coded using a five-point scale with the following options: "Always", "Often", "Occasionally", "Rarely", and "Never". The responses were then dichotomized. "Always" and "Often" were considered as LDAB adoption and assigned a value of (1), while "Occasionally", "Rarely", and "Never" were considered as a lack of LDAB adoption and assigned a value of (0). These values were then summed to obtain a measure of adaptive behaviour.

In subsequent questions assessing TPB constructs theoretically associated with adaptive behaviour, it is prohibitively time-consuming to repeat each question for each specific LDAB. To circumvent this issue while still preserving the participants' understanding of the

Table 2. Index of Lyme disease adaptative behaviours (LDAB).

1. Looking into ways to prevent Lyme disease.
2. Wearing clothes that cover more skin.
3. Tucking in clothes when doing outdoor activities.
4. Using bug repellent when outdoors.
5. Walking on cleared paths and trails, avoiding tall grass during outdoor activities.
6. Wearing light-coloured clothing to make it easier to check for ticks during outdoor activities.
7. Examining your body for ticks and removing them immediately after being outdoors.
8. Examining clothes and items to avoid bringing ticks into your home after being outdoors.
9. Putting clothes in the dryer for 6 minutes to eliminate ticks that you may have brought in from outdoors.
10Increasing the frequency of lawn maintenance, including mowing.

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correspondence between the constructs and behaviours, we follow Fishbein & Ajzen's [59] suggested method of reminding participants to keep the behaviours constituting the response variable in mind when answering subsequent questions.

Intention. To assess participants' intention to adopt preventive behaviours against Lyme disease, three items were averaged based on their level of agreement (see Table 3).

Attitude toward adaptation to Lyme disease. To assess participants' attitude toward adaptation to Lyme disease, we used 6-point differential semantic scales (see Table 3). Responses to three items were then averaged to obtain a measure of attitude.

Perceived social norms. Participants' perception of social norms regarding the adoption of Lyme disease preventive behaviours was assessed by averaging the degree of agreement with three items each scored on a 6-point scale (see Table 3).

Perceived behavioral control. The participants' perceived control over LDAB was assessed based on their responses to three items (see Table 3). Their responses to the three items were averaged to obtain a measure of perceived behavioral control.

Behavioral beliefs. An expectancy-value index [58] was used to assess participants' beliefs about Lyme disease prevention. Participants were asked to rate each of the five consequences elicited in the pilot study in terms of its perceived likelihood and the subjective value of each of these consequences (see Table 3). A behavioral belief score was obtained by multiplying the score for the likelihood of an outcome by the score of its desirability. These multiplicative items were then averaged to obtain an overall score of the behavioral beliefs construct.

Normative beliefs. These beliefs were measured first by asking participants how much they believed each of the seven normative reference groups identified in the pilot study expected them to adopt Lyme disease adaptation behaviours. Second, they were asked to indicate whether they comply with these expectations (see Table 3). These multiplicative items were averaged to obtain an overall score for the normative beliefs construct.

Control beliefs. Participants' beliefs about facilitating and impeding factors related to the adoption of LDAB were assessed by asking participants to rate each of five factors elicited in the pilot study in terms of its perceived expected occurrence, and the extent to which they would facilitate/hinder the adoption of the behaviour (see Table 3). These multiplicative items were then averaged to obtain an overall score for the control beliefs construct.

Statistical analyses

First, psychometric analyses were conducted to test the reliability of each scale. Item-total correlation was used to exclude items with low discrimination. The minimum threshold for inclusion based on item-total correlation was 0.2 [86]. Below this threshold, items were removed using a backward selection process; the item with the lowest value under 0.2 was removed first

Table 3. Theory of planned behavior constructs.

Construct	Response options	Items	Mean ±SD	Theoretical minimum and maximum	Item discrimination / item-total correlation	Cronbach Alpha
Intention to adopt LDAB (3 items)	6-point scale: Strongly disagree to Strongly agree	• You plan to adopt measures and behaviours that can protect you from Lyme disease during the next tick season (May to December).	4.92 ±1.22	[1, 6]	0.72	0.87
		• In general, you want to adopt measures or behaviors to protect yourself from Lyme disease during the next tick season (May to December).	4.96 ±1.18	[1, 6]	0.79	
		• You are very likely to adopt measures and behaviors that can protect you from Lyme disease during the next tick season (May to December).	4.75 ±1.24	[1, 6]	0.76	
Attitude towards LDAB (3 items)	6-point semantic differential scales	If the next tick season (May to December) you adopt measures or behaviors to protect yourself from Lyme disease, do you think it will be. . .				0.85
		• Unhealthy (1) to Healthy (6)	5.14 ±1.13	[1, 6]	0.70	
		• Irresponsible (1) to Responsible (6)	5.39 ±1.04	[1, 6]	0.73	
		• Dangerous (1) to Safe (6)	5.24 ±1.09	[1, 6]	0.70	
Perceived social norms (3 items)	6-point scale: Strongly disagree to Strongly agree	• People important to you will appreciate your adoption of measures and behaviors that can protect you from Lyme disease during the next tick season (May to December).	4.92 ±1.28	[1, 6]	0.78	0.86
		• Your family and friends will encourage your adoption of measures and behaviors that can protect yourself from Lyme disease during the next tick season (May to December).	4.40 ±1.52	[1, 6]	0.65	
		• People with opinions you trust will agree with your adoption of measures and behaviors that can protect yourself from Lyme disease during the next tick season (May to December).	4.99 ±1.23	[1, 6]	0.74	
Perceived behavioral control (3 items)	6-point scale: Very difficult to Very easy	• Indicate the degree of difficulty involved when adopting measures and behaviours that can protect you from Lyme disease during the next tick season (May to December).	4.29 ±1.23	[1, 6]	0.57	0.69
	6-point scale: Strongly disagree to Strongly agree	• You will develop an understanding and willingness to adopt measures and behaviors that can protect you from Lyme disease during the next tick season (May to December).	4.82 ±1.14	[1, 6]	0.55	
	6-point scale: Strongly agree to Strongly disagree	• You think it will be too demanding for you to adopt these measures and behaviors to protect yourself from Lyme disease during the next tick season (May to December).	3.70 ±1.55	[1, 6]	0.35	
Behavioral beliefs (5 pairs of multiplicative scales)	Outcome expectations 6-point scale: Very unlikely to Very likely × Outcome desirability 6-point scale: Very undesirable to Very desirable	According to you, are the following outcomes likely or unlikely to occur if you adopt measures and behaviours that can protect you from Lyme disease during the next tick season (May to December)? Indicate the degree of desirability or undesirability you attach to the following situations.				0.76/0.85[a]
		• The health of your loved ones will be protected	3.36 ±2.97	[-6.25, 6.25]	0.65/0.70[a]	

(*Continued*)

Table 3. (Continued)

Construct	Response options	Items	Mean ±SD	Theoretical minimum and maximum	Item discrimination / item-total correlation	Cronbach Alpha
		• Protecting yourself from ticks will be too unpleasant	0.40 ±3.10	[-6.25, 6.25]	0.11/—-[a]	
		• Tick bites will be avoided	3.08 ±3.03	[-6.25, 6.25]	0.61/0.66[a]	
		• You will be able to continue to participate in outdoor activities that are important to you.	3.44 ±2.93	[-6.25, 6.25]	0.62/0.65[a]	
		• The risk of transmitting Lyme disease will be reduced.	3.36 ±2.92	[-6.25, 6.25]	0.70/0.74[a]	
Normative beliefs (7 pairs of multiplicative scales)	Normative expectations 6-point scale: Strongly disagree to strongly agree. × Motivation to comply with the referents 6-point scale: Strongly disagree to strongly agree.	The following people or groups believe that you should adopt measures and behaviours that can protect you from Lyme disease during the next tick season (May to December). You should listen to advice from the following people regarding the adoption of measures and behaviours that can protect you from Lyme disease.				0.94
		Health specialist	10.72 ±5.85	[−15, 15]	0.85	
		Your friends and family (spouse, children, etc.)	8.22 ±6.58	[−15, 15]	0.70	
		Public health officials	10.21 ±6.01	[−15, 15]	0.87	
		Acquaintances who have already contracted the disease	9.88 ±6.70	[−15, 15]	0.66	
		Researchers and scientist	10.61 ±6.01	[−15, 15]	0.84	
		The provincial government	8.68 ±6.34	[−15, 15]	0.82	
		Municipal governments	8.84 ±6.27	[−15, 15]	0.83	
Control beliefs	Presence of factors that may facilitate or impede performance of behaviors 6-point scale: Strongly disagree to strongly agree × Perceived power of each control factor 6-point scale: Strongly disagree to strongly agree.	You expect the following to occur during the next tick season (May to December). The following conditions and situations would facilitate/hinder your adoption of measures and behaviours that can protect you from Lyme disease during the next tick season (May to December).				0.37/0.48/ 0.68[a]
		• You will experience discomfort while adopting measures and behaviours that can protect you from Lyme disease.	-1.02 (2.70)	[-6.25, 6.25]	-0.01/—-/—-[a]	
		• You will develop a good understanding of measures and behaviours recommended by experts to protect you from Lyme disease.	2.87 (2.68)	[-6.25, 6.25]	0.36/0.47/0.56[a]	
		• You will lack the items required to protect yourself from Lyme disease (clothing, insect repellent, etc.).	-0.33 (3.20)	[-6.25, 6.25]	0.07/-0.06/—-[a]	

(*Continued*)

Table 3. (Continued)

Construct	Response options	Items	Mean ±SD	Theoretical minimum and maximum	Item discrimination / item-total correlation	Cronbach Alpha
		• Fear will motivate you to adopt measures and behaviours that can protect you from Lyme disease.	1.88 (2.88)	[-6.25, 6.25]	0.30/0.39/0.46[a]	
		• You will learn about areas and cities with a high risk of Lyme disease transmission.	1.53 (3.04)	[-6.25, 6.25]	0.23/0.33/0.48[a]	

[a] Multiple item-total correlation and alpha are presented because one or more items were removed from the scales. Consequently, these values changed each time an item was removed.

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and the statistics were recalculated before removing any further items from the scale. Additionally, Cronbach's alpha was calculated and reported for each resulting scale. An alpha value of 0.7 is widely considered an acceptable threshold for internal consistency of a scale and was therefore used here [87]. Second, structural equation modelling (SEM) with Mplus 8.3 [88] was performed to test the TPB model and identify which of the three constructs of the TPB (attitudes, social norms, and perceived behavioral control) significantly predicted the intention to adopt LDAB (Objective 1). Third, three multiple regression analyses were performed using Mplus 8.3 to identify behavioral, normative and control beliefs significantly related to attitudes, social norms, and perceived control, respectively (Objective 2).

The Tucker Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Comparative Fit Index (CFI) were used in the SEM analysis to assess model fit. The TLI and the CFI indicate a good or excellent model fit when their value is greater than or equal to 0.90 or 0.95, respectively. A RMSEA value between 0.06 and 0.08 indicates an acceptable model fit, while a value lower than 0.06 indicates an excellent fit [89, 90].

Results

A total of 2,011 respondents (1,049 identifying as women [52.2%]; 961 as men [47.8%]; and 1 as other [0.1%]) completed the online survey between February 1 and March 2, 2021. The response rate was 11.3%.

Reliability of the scales

Cronbach's alphas, means, standard deviations, and item-total correlations (item discriminations) are presented in Table 3. After examining the item-total correlation, three items were removed due to their failure to meet the 0.2 threshold: one behavioral belief ("Protecting yourself from ticks will be too unpleasant"; rho = 0.11), and two control beliefs ("You will experience discomfort while adopting measures and behaviours that can protect you from Lyme disease"; rho = -0.01; and "You will lack the items required to protect yourself from Lyme disease"; rho = 0.07). Following this step, the results of the psychometric analyses showed that all the alpha coefficients were adequate, albeit with two scales (perceived behavioral control and control beliefs) showing values slightly below 0.70 (see Table 3).

Testing the TPB model

The means and standard deviations of the variables are shown in Table 4. The results showed that less than half of the suggested LDAB were adopted by participants (M = 4.24/10). However, according to the mean responses on the respective six-point scales, they reported a high

Table 4. Descriptive analyses and correlation matrix of TPB constructs.

Variables	Theoretical ranges	# Items	*M* ± *SD*	1	2	3	4	5	6	7	8
1. Behaviours (LDAB)	0–10	10	4.24 ± 2.32	–							
2. Behavioral intentions	1–6	3	4.88 ± 1.08	0.43**	–						
3. Attitudes	1–6	3	5.26 ± 0.95	0.22**	0.55**	–					
4. Perceived social norms	1–6	3	4.77 ± 1.18	0.31**	0.66**	0.45**	–				
5. Perceived behavioral control	1–6	3	4.27 ± 1.02	0.37**	0.68**	0.42**	0.52**	–			
6. Behavioral beliefs	-6.25-+6.25	4	3.31 ± 2.46	0.15**	0.35**	0.47**	0.31**	0.29**	–		
7. Normative beliefs	-15-+15	7	9.60 ± 5.31	0.26**	0.64**	0.61**	0.63**	0.48**	0.44**	–	
8. Control beliefs	-6.25-+6.25	3	2.10 ± 2.25	0.33**	0.53**	0.41**	0.41**	0.44**	0.25**	0.41**	–

**p < 0.01

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intention to adopt these behaviours (M = 4.88/6) and a positive attitude toward LDAB (M = 5.26/6). Participants also indicated a high perceived social pressure to adopt these behaviours (M = 4.77/6), and a strong perception of control over LDAB (M = 4.27/6).

The results in Table 4 also demonstrate significant correlations between all TPB variables. More precisely, intentions correlated better with predictive variables (attitudes, perceived social norms, and perceived control over behaviours) than with the LDAB index. Furthermore, behavioral, normative, and control beliefs are significantly related to their associated construct: attitudes (r = 0.47), perceived social norms (r = 0.63), and perceived behavioral control (r = 0.44). In other words, these results indicate that the behavioral, normative, and control beliefs can explain the three main determinants of behavioural intention according to the TPB, respectively [60].

In addition, according to the coefficients of determination (R^2), the predictive variables of the TPB model account for 94.4% of people's intentions to adopt LDAB (Fig 2). While this exceeds the R^2 values commonly observed in other TPB studies, including transversal studies where intentions and behaviour are measured at the same timepoint, our large sample size should preclude issues related to overfitting [59]. In contrast, the predictive variables explain 28.3% of the variance in reported LDAB (Fig 2). The model's fit to the data was good to excellent: CFI = 0.93, TLI = 0.92 and RMSEA = 0.06.

The results also indicate that intentions are significantly associated with reported LDAB ($\gamma = 0.53$, $p < 0.01$), and all proximal determinants of the TPB: attitudes toward LDAB ($\gamma = 0.09$, $p < 0.01$), perceived social pressures to adopt LDAB ($\gamma = 0.18$, $p < 0.01$), and perceived control over LDAB ($\gamma = 0.77$, $p < 0.01$). In addition, every belief composite (behavioral, normative, and control beliefs) is significantly related to its respective proximal determinant ($p < 0.01$).

Effects of beliefs

This section examines which behavioral, normative, and control beliefs are significantly related to attitudes towards LDAB, perceived social norms, and perceived control over LDAB, respectively. Indeed, our final scales measured four behavioral beliefs, seven normative beliefs and three control beliefs. These are all listed in Table 3. The theoretical minimum and maximum values, as well as the observed mean and standard deviation are also presented.

The four behavioral beliefs accounted for 22.7% of the variance in attitudes toward adopting LDAB. The estimated effects of all of these beliefs were statistically significant: "I will protect the health of my loved ones" ($\gamma = 0.11$, SE = 0.03, $p < 0.0001$); "I will avoid tick bites" ($\gamma = 0.11$, SE = 0.03, $p < 0.0001$); "I will be able to continue to participate in outdoor activities that

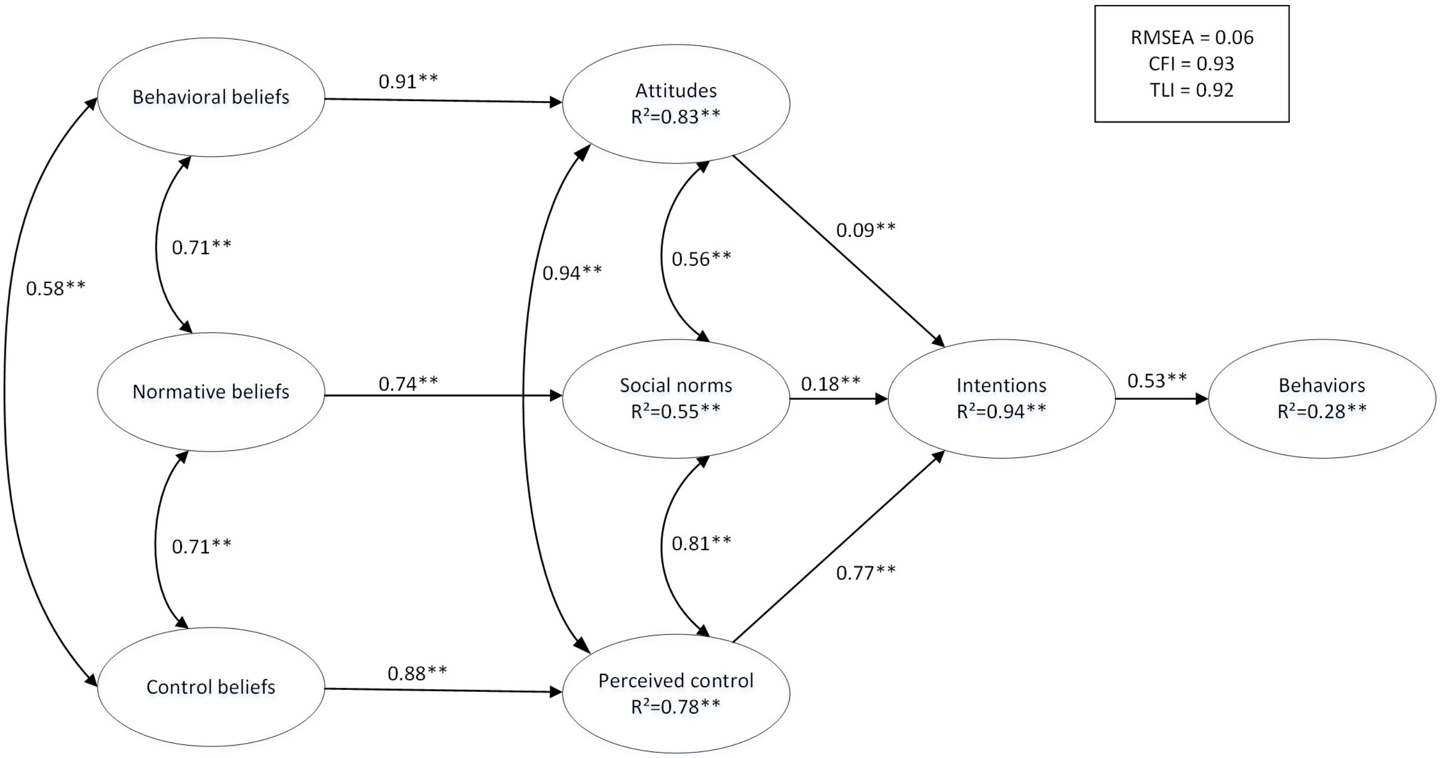

Fig 2. TPB model predicting people's adaptive behaviours toward Lyme disease. *p < 0.05, **p < 0.01, ***p < 0.001.

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are important to me" (γ = 0.18, SE = 0.03, $p < 0.0001$); "I think that the risk of transmitting Lyme disease will be reduced" (γ = 0.17, SE = 0.03, $p < 0.0001$).

The seven normative beliefs explained 45.7% ($p < 0.0001$) of the variance in perceived social norms. The estimated effects of two of the seven normative beliefs were significant, particularly the beliefs related to the perceived approval of friends and family (γ = 0.45, SE = 0.03, $p < 0.0001$), and to a lesser extent, of the municipal government (γ = 0.10, SE = 0.04, $p < 0.01$).

Control beliefs accounted for 25.2% of the variance ($p < 0.0001$) in perceived control, with two facilitating factors having significant estimated effects, these were: "Having a good understanding of measures and behaviours that are recommended by experts to prevent Lyme disease" (γ = 0.44, SE = 0.02, $p < 0.0001$), and "learning about areas and cities with a high risk of Lyme disease transmission" (γ = 0.09, SE = 0.02, $p < 0.0001$).

Discussion

The results showed that the population of the province of Quebec is still in the early stages of adopting preventive behaviours towards Lyme disease. Despite our respondents residing in high Lyme disease risk regions, they adopted on average 4.19 of the 10 behaviours included in the LDAB index in 2018 [56], while in 2021 the average was 4.24. These results are consistent with those from other studies in Canada [44, 52, 91] and in other countries where Lyme disease is endemic, including the United States [49], France [92] and the Netherlands [93]. Previous studies conducted in regions of the province of Quebec where Lyme disease incidence is the highest (Montérégie and Estrie regions) also showed that the adoption of preventive behaviours was low [52, 91]. These results suggest that more tailored messages and educational campaigns aiming to promote these preventive behaviours should be developed (e.g., public awareness campaigns, training for medical professionals, preparation of government documents). To design such efficient interventions, we need to better understand the psychosocial underpinnings of expert-recommended preventive behaviours, and the TPB's behavioural, normative and control belief constructs provide a robust framework for this. Essentially, interventions should challenge people's beliefs that are in opposition to the desired adaptive behaviours using information that engages their existing supportive beliefs, or that encourage them to form new ones in line with the desired behaviours [76, 94]. The current study sheds some light on this subject by identifying certain specific and actionable behavioral, normative, and control beliefs that underlie Quebecers' more general attitudes, social norms and perceptions of behavioural control determining their intention to adopt LDAB.

The first objective of this study was to predict and explain individuals' adaptive behaviour to Lyme disease using the full TPB model. According to the results, attitudes, perceived social norms, and perceived behavioral control accounted for a large proportion of the variance in intentions to adopt Lyme disease adaptive behaviours (LDAB). These intentions were also a good predictor of self-reported LDAB. Particularly noteworthy is the strong estimated effect of perceived behavioral control on intentions and presumably, behaviour (through intentions). This finding emphasizes the importance of removing potential barriers and creating conditions that will encourage the adoption of LDAB, which has also been highlighted by other studies [49, 91, 95]. To a lesser extent, perceived norms and attitudes are also linked to intentions and behaviour according to our model, and thus our results suggest that interventions must subjectively transmit accurate information that links adaptation to positive outcomes and social norms followed by certain referent individuals or groups who support adopting the adaptive behaviours or who have adopted them themselves. Though these findings on the importance of constructs such as perceived control on intentions to adapt to Lyme disease are significant in themselves, the theoretical and practical relevance of this study lie in our identification of the specific beliefs that should be targeted in interventions.

Examination of the specific control beliefs that predicted adaptation through overall perceptions of control revealed Quebec residents' view that comprehending the measures and behaviours recommended by experts to protect themselves from Lyme disease and being familiar with high Lyme disease risk areas will facilitate adaptation. This finding is consistent with the results obtained by Beck et al. [49], who found that lack of awareness was a barrier to practicing prevention behaviours. Anecdotally, this finding is also possibly reflected in the beliefs and TPB constructs' excellent ability to predict intentions to adopt LDAB in the future, but limited ability to explain variance in current LDAB patterns, as respondents simply may not have had prior knowledge of many of the behaviours at the time of the survey. Though one's internal integration and understanding of communicated information is an important process in surmounting these knowledge barriers, there is an important external component to these control beliefs. Indeed, these barriers can largely be overcome with improved accessibility of information, both in terms of ease of availability and intelligibility. Therefore, campaigns aiming to favour LDAB adoption should emphasize educating the public on the behaviours and raising awareness on the locations of high-risk areas. Fortunately, quality resources on endemic areas and tick detection in Québec and Canada exist (e.g., https://www.hopkinslymetracker.org/explorer/); these should be further developed and awareness of them should be promoted.

The results also showed that four behavioural beliefs have significant associations with LDAB via attitudes and intentions. Three of these beliefs (i.e., adopting LDAB will: 1) avoid tick bites, 2) protect the health of one's loves ones, and 3) reduce the risk of transmitting Lyme disease) were related to the same cognitive advantage: adapting to Lyme disease has a protective effect on health. This is not surprising, considering that Lyme disease can have severe and long-lasting consequences [35, 36]. This suggests that this health protection benefit is associated with respondents' positive attitudes toward LDAB. The fourth behavioral belief, on the other hand, relates more to preserving one's lifestyle and quality of life, as it cites the ability to continue to pursue outdoor activities as an advantage of LDAB. Thus, educational messages must also strengthen this last belief since the practice of outdoor activities is a lifetime objective for many people. This last result is consistent with the Theory of Reasoned Goal Pursuit (TRGP) [96], an extension of the TPB. This theory postulates that a person's current set of goals reinforce their motivation to perform a specific behaviour [97]. In our case, a person could have a high intention to protect themselves against ticks and eventually adopt the proposed adaptive behaviours because they align with their current objective to practice outdoor activities. Our results show that the population already has a positive perception of outcomes following LDAB adoption (the behavioural beliefs' average score is 3.31 on a scale ranging from -6.25 to +6.25) and a strong positive attitude toward the adoption of LDAB (mean attitude score of 5.26 out of 6), which bodes well for increasing adoption of LDAB if they become socially normalized and knowledge barriers to their adoption are removed.

The results also revealed that two normative beliefs are associated with LDAB via social norms and intentions. This finding demonstrates that the approval of groups of influence such as friends, family as well the municipal government is important for LDAB adoption. Therefore, to be effective, a norm-based intervention should focus on encouraging people to not only adopt LDAB themselves but also support their loved ones' adaptation, and municipal authorities should be directly involved in LDAB advocacy and awareness raising in at-risk constituencies. This participation could both improve social normalization of LDAB and harness aforementioned levers to behaviour adoption (knowledge of behaviours and knowledge of at-risk areas). Some municipalities in Quebec have already taken steps in this direction. This is the case, for example, of the municipality of Bromont, which is located in a Lyme disease endemic region in Southern Quebec. This municipality launched a project in 2019 to raise awareness and engage citizens in adopting preventing behaviors in partnership with the Estrie Public Health Direction and the University of Montreal [98, 99]. On their website, users can find highly useful resources such as posters and videos about the behaviours to adopt, where on one's body ticks tend to be located, and periods of the year they are active. Municipalities should also be involved in disseminating the aforementioned maps and interactive tools identifying areas at risk for ticks or developing their own.

The present research has significant strengths, such as a strong theoretical framework, a sample population that resembles the target population, a validated behaviour index, and the use of advanced statistical modelling techniques, but its limitations should also be considered when interpreting the findings. First, we describe LDAB as behaviours that can protect individuals from Lyme disease in our survey questions, which may introduce an element of social desirability and bias participants' responses; this is a limitation common to TPB research on health behaviours [100] and has been deemed a minor issue [101]. Additionally, the observational cross-sectional design of this study precludes inferring causal relationships between variables. Though transversal TPB studies have repeatedly demonstrated success at predicting behaviour [59], a suggestion for future research would be to conduct a longitudinal study to test whether the beliefs significantly associated with LDAB in the present study can predict these behaviours over a period of one year, the target timeframe proposed in the survey questions. A second limitation involves the overall low response rate (11.3%, although typical for a large-scale study), which may have impacted the generalizability of results. Similarly, since the present study considered only adult respondents, inferences derived from its results are limited to that population. Future research should attempt to perform a similar study with adolescents and children, as well as their parents, as the latter are often making the decision for their children [54]. As a first step, we suggest that the LDAB index be adapted and validated for this young population. Although consistent with findings in other countries, another limitation is that the study's sample of adaptive behaviours may not necessarily represent all possible adaptive behaviours. For instance, in contrast to Beck et al. [49], "Wear permethrin-treated clothing" was not an indicator in our LDAB index because it was not recommended as a behaviour to adopt in the province of Quebec at the time of data collection. Finally, as this study focused on identifying beliefs in Quebec's high-risk regions only, we also suggest that future studies evaluate beliefs in regions at high as well as low Lyme disease risk areas in order to facilitate comparison and distinguish differences.

Conclusion

Our results show the need to develop innovative ways to motivate people to engage in LDAB. Using a well-known social-cognitive model of human behaviour, the study examined how tick-exposed individuals make decisions and identified specific factors that can raise awareness of Lyme disease risk. In the model, attitude, social norms, and perceived control were statistically significantly associated with the intention to adapt, whereas intent itself was strongly associated with adaptive behaviour. This is in line with the TPB's postulate that people's behaviours (in this case, LDAB) involve a measure of reasoning and planning but can also follow spontaneously and automatically from their belief system [60]. This study has identified beliefs that need to be strengthened or changed to motivate people to adopt LDAB in order that the desired behaviours became habitual.

Supporting information

S1 Data. Data used in the study.
(XLSX)

S1 File.
(DOCX)

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