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Deriving low-risk gambling limits from longitudinal data collected in two independent Canadian studies

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ABSTRACT

Aims To derive low risk gambling limits using the method developed by Currie *et al.* (2006) applied to longitudinal data. **Design** Secondary analysis of data from the Quinte Longitudinal Study (n 3054) and Leisure, Lifestyle and Lifecycle Project (n 809), two independently conducted cohort studies of the natural progression of gambling in Canadian adults. **Setting** Community dwelling adults in Southeastern Ontario and Alberta, Canada. **Participants** A total of 3863 adults (50% male; median age 44) who reported gambling in the past year. **Measurements** Gambling behaviours (typical monthly frequency, total expenditure and percentage of income spent on gambling) and harm (experiencing two or more consequences of gambling in the past 12 months) were assessed with the Canadian Problem Gambling Index. **Findings** The dose response relationship was comparable in both studies for frequency of gambling (days per month), total expenditure and percentage of household income spent on gambling (area under the curve values ranged from 0.66 to 0.74). Based on the optimal sensitivity and specificity values, the low risk gambling cut offs were eight times per month, $75CAN total per month and 1.7% of income spent on gambling. Gamblers who exceeded any of these limits at time 1 were approximately four times more likely to report harm at time 2 [95% confidence interval (CI) 2.9 6.6]. **Conclusions** Longitudinal data in Canada suggest low risk gambling thresholds of eight times per month, $75CAN total per month and 1.7% of income spent on gambling, all of which are higher than previously derived limits from cross sectional data. Gamblers who exceed any of the three low risk limits are four times more likely to experience future harm than those who do not.

Keywords Gambling harms, longitudinal cohort study, low risk gambling limits, problem gambling, prevention, receiver operating characteristic analysis, risk curves.

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INTRODUCTION

Gambling disorders remain a significant public health con cern both in Canada [1] and internationally [2 4]. In the latest revision to the DSM, pathological gambling was dropped in favour of the term 'gambling disorder' [5]. While gambling disorder impacts approximately 1 3% of the general population [3], another 4 10% of the popula tion are frequent gamblers (gamble at least twice weekly) or report symptoms of gambling disorder that lie beneath the clinical threshold [4]. There is no single, unifying theo retical model on the development of gambling problems, and those proposed have focused almost exclusively on the aetiology of pathological gambling [6]. A combination of vulnerability (e.g. impulsivity, family history, mental illness), socio economic and environmental (e.g. availability) factors are thought to interact to increase an individual's risk of gambling disorder. The development of lower severity gambling problems (also referred to in the lit erature as 'problem gambling' or 'moderate risk' gambling) is thought to be influenced by a similar set of psychological, sociological and environmental risk factors. However, there is compelling new evidence from longitudinal research that amount of gambling itself is one of the strongest predictors of future gambling problems [7 10]. The Leisure, Lifestyle and Lifecycle Project (LLLP) and Quinte Longitudinal Study (QLS) were the first population based longitudinal studies to test a shared, multi factorial model of the development of gambling problems over time. In addition to individual dispositional variables (vulnerability factors, cognitive fallacies, etc.), first onset of gambling problems was associated strongly with more frequent and heavier gambling involvement at baseline [7,8].

There has been considerable interest among researchers to study the 'dose response' relationship between gambling intensity and associated harms [11 14]. Research shows clearly that the more one gambles, the greater the likelihood of harm. This finding parallels the wealth of empirical data amassed during the last 30 years on the relationship between alcohol consumption and risk of health consequences and social harm [15 18]. This research was instrumental in the formation of the low risk drinking limits promoted in many countries to help drinkers moderate their consumption [19]. While alcohol related harms are defined generally as physical health conditions arising from excess consumption (e.g. cancers, diseases of various organ systems, neurological conditions), the definition of harm within the context of excess gambling has been more difficult to standardize. An Australian team of researchers recently undertook a comprehensive study of gambling related harms. In their report, *Assessing gambling-related harm in Victoria: a public health perspective* [20], a taxonomy of seven categories of gambling related harms is proposed: financial harm; relationship disruption, conflict or breakdown; emotional or psychological distress; physical health problems; cultural harm (e.g. not meeting social expectations); reduced performance at work or study; and criminal activity.

Our research team has investigated how the dose response relationship between gambling intensity and harm can be used to establish low risk gambling limits [11]. This research has used cross sectional survey data from national and regional gambling prevalence studies to identify the optimal threshold for minimizing harm. Using this method, the low risk limits derived from cross sectional data were gambling no more than three times per month, spending no more than $1000CAN per year, and spending no more than 1% gross household income on gambling. Exceeding these limits was associated with a significant increase in the risk of harm independent of other known predictors of problem gambling. These limits were validated in a subsequent study using a different data set [21].

Weinstock and colleagues developed a similar set of moderate gambling limits for pathological gamblers (once per month or less; spending no more than 2% income on gambling) that differentiated problem free and symptomatic gambling reliably [12]. A more recent investigation involving media recruited adults including individuals with a diagnosed mood disorder identified the optimal cut offs for avoiding harm from gambling. Using the same definition of harm employed by our research group (reporting two or more consequences of gambling), the optimal low risk limits were considerably more conservative than other studies: gambling no more than once per month, spending less than 23 minutes gambling per session and spending less than $25US per month [13]. Conservative limits were also reported in a German cross sectional investigation involving a representative sample of more than 15 000 adults. Gambling more than 11 days in the past year increased the risk of harm significantly (defined by endorsing one or more DSM 5 symptoms for gambling disorder) after accounting for age and other demographic characteristics [14].

Although these findings support the overall validity of the low risk gambling limits, the proposed limits were all derived from cross sectional survey data. For the present investigation, we sought to derive a new set of low risk gambling limits from longitudinal data collected in two independently conducted population cohort studies of gambling habits. The specific goals of this research were to: (1) derive optimal low risk cut offs for gambling frequency and expenses using longitudinal data; (2) compare the limits with those derived from cross sectional data; and (3) estimate the risk of future harm if gamblers exceed any of the low risk limits.

METHOD

Leisure, Lifestyle and Lifecycle Project (LLLP)

The LLLP, described in detail in other sources [22,23], was a prospective 5 year panel study of 1808 adolescents and adults living in rural and urban Alberta. Briefly, data were collected during four waves (covering the years 2006 11) on multiple factors theoretically linked to the aetiology and natural progression of gambling habits. Data were collected using a combination of face to face, telephone and on line methods. Random digit dialling (RDD) recruited participants from the general population in Alberta as well as a proportion of individuals who were likely to develop gambling problems during the longitudinal follow up period (individuals who were above the 70th percentile in gambling expenditure or frequency based on national population data). Additional RDD sampling and media recruitment was used to recruit the 'at risk' gambling sample (n 524; 29%). Participants completed a battery of self report and administered tests covering gambling, substance use, personality, intelligence, mental health, life events and social environment. The present study uses data on 809 adults who reported gambling at time 1, completed the time 2 assessment and had valid data for gambling related harms. The attrition rate between times 1 and 2 in the LLLP was 17%.

Quinte Longitudinal Study (QLS)

The QLS was initiated at the same time as the LLLP [8]. It recruited 4123 Ontario adults from the Quinte Region in southeastern Ontario, Canada. The time frame (also 2006 11), goals and content of the baseline and follow up assessments were very similar to the LLLP. Sampling was also performed via RDD within the Quinte region. Al though adolescents were not recruited, a similar propor tion (26%) of adults with 'at risk' gambling characteristics (defined as spending at least $10 per month on gambling in the past year or engaging in slot machines or horse racing) was recruited during the initial wave of RDD. With the intention of matching the LLLP sample, the present study focused on adults who reported gambling at time 1, participated in the time 2 data collection and had valid data for gambling related harms (*n* 3054). The rate of attrition between times 1 and 2 in the QLS was 4%, much lower than the LLLP, although both studies employed a similar rate of remuneration for participants (QLS: $50CAN versus LLLP: $75CAN for initial assess ment). The interval between the start of each assessment was 12 months in QLS and 19 months in LLLP.

Assessment of gambling

Although both studies included a battery of assessment measures, our primary interest was the data collected on gambling activities (the intensity and breadth of gambling habits) and gambling related harm. Data on gambling ex penditures were comparable in the QLS and LLLP. Partici pants were asked to estimate over the past year the amount spent on each form of gambling in a typical month. The total expenditure on all forms of gambling was estimated by summing the expenditures for the indi vidual gambling formats. For the statistical analysis, nega tive values (representing self reported losses) were converted to positive and the positive values (indicating wins) recoded as zero, reflecting that the participant spent no money on gambling during the reference period. The percentage of income spent on gambling was calculated by dividing the total expenditure for the month by the par ticipant's gross monthly household income (to a maximum of 100%).

Frequency of gambling was also assessed separately for each gambling format. The original Canadian Problem Gambling Index (CPGI) seven point categorical scale [24] used in the LLLP was converted to a quantitative scale to estimate number of gambling days each month (1 5 times/year 0.25 days; 6 11 times/year 0.5 days; 1 time/month 1 day; 2 3 times/month 2.5 days; once per week 4 days; 2 6 times/week 16 days, or; daily 30 days). The QLS used a different categorical scale that was also converted to a quantitative value representing the number of days gambled per month (less than once a month 0.5 days; once a month 1 day; 2 3 times a month 2.5 days; once a week 4 days; 2 3 times a week 10 days; 4 or more times a week 16 days). The maximum frequency of gambling was calculated by summing the frequency values for the individual gambling formats resulting in a value ranging from 0 to 30 times per month. This resulted in a composite measure that reflected the number of days in a typical month the individual reported gambling. For all measures, the reporting period was the last 12 months.

Gambling related harms were assessed using the Prob lem Gambling Severity Index (PGSI), a nine item scale that assesses consequences and behavioural symptoms of prob lem gambling in the past 12 months. Although total PGSI score is reported for descriptive purposes, the main analy ses used to determine the low risk limits did not use the PSGI scoring categories. Only the seven PGSI items pertaining to consequences were used: feeling guilty, bet ting more than can afford, recognition of a problem, health problems, financial problems, being criticized by others and borrowing money to gamble. Each consequence was scored dichotomously (0 never; 1 sometimes, most of the time or almost always), with harm defined as having a total score of two or higher. The time frame for all items was the past 12 months. In previous work we found this definition of harm to have the best psychometric properties [highest area under the curve (AUC), sensitivity and speci ficity values] compared to alternative definitions [25]. Al though not as comprehensive as the Victorian taxonomy, the abbreviated list of PGSI consequences covered harms in the financial, relationship and health domains. We also rationalized that individuals endorsing gambling related problems in two different domains could be viewed reason ably as beginning to experience harm related to their gam bling. Using this scoring, the respondent needs to report at least two consequences of gambling in the past 12 months to experience harm. The internal consistency (Cronbach's alpha) for this subset of PGSI items was adequate in both the LLLP (0.80) and QLS (0.79) samples.

Data analysis

Sampling weights were developed for the LLLP but not the QLS, therefore all analyses were conducted on the un weighted data for both samples. Risk curves were calcu lated separately for the principal dimensions of gambling intensity: frequency of any gambling (days) in a typical month; typical expenditure (net loss) on all forms of gam bling in a month; and percentage of gross monthly house hold income spent on all forms of gambling in a month. Gambling intensity values at time 1, which represent typi cal monthly activity for the past year, were plotted against the proportion reporting two or more harms from gam bling at time 2 (the reference period was also the last year). Group categories of approximately equal size were created for gambling frequency, expenditure and percentage of in come and used for the *x* axis on each risk curve.

For comparison purposes, the risk curves and optimal cut offs were also calculated for the time 1 cross sectional data (intensity of gambling at time 1 predicting harm at time 1). Curves were first plotted for men and women sep arately, but similar to prior studies [21] there were no dis cernible gender differences, hence only the combined analyses are reported. Similarly, risk curves for younger versus older gamblers (based on a median split) showed no differences.

The optimal low risk limit for gambling participation was identified using receiver operating characteristic (ROC) analysis. With this approach the performance of var ious cut off levels over the complete range of non zero scores was tested. The AUC, a general index of the accuracy of prediction, was computed along with the 95% confi dence interval (CI) around the estimate [26]. The nominal AUC value was assessed against established interpretative guidelines: 0.5 0.7 'low accuracy;' 0.7 0.9 'moderate accuracy;' > 0.9 'high accuracy' [27]. In one set of anal yses, the optimal cut off score for each parameter was cho sen based on the Youden Index [28], an approach designed to maximize the discrimination between the presence or absence of harms, giving equal weighting to sensitivity and specificity. For some parameters, this resulted in very low specificity values (< 0.50). Therefore, an alternative method was employed in which chosen cut offs maximized sensitivity while maintaining specificity at 0.70 or higher.

As a final step, a logistic regression model was used to estimate the odds of experiencing future harm if a gambler exceeds each threshold. The cut offs were entered into the models together to show the power of prediction for each cut off independent of the other thresholds. We also esti mated the odds of future harm if a gambler exceeded any of the limits, and if a gambler exceeded all three low risk limits.

Table 1 Leisure, Lifestyle and Lifecycle Project (LLLP) and Quinte Longitudinal Study (QLS): demographics and gambling characteristics at time 1.

	n (%) or mean (SD)	
Variable	*QLS (n = 3054)*	*LLLP (n = 809)*
Gender		
Male	1432 (46.9)	348 (43.0)
Female	1622 (53.1)	461 (57.0)
Marital		
Single	352 (11.5)	301 (37.2)
Married/common law	2199 (72.0)	408 (50.4)
Separated/divorced/widow	503 (16.5)	98 (12.4)
Ethnicity		
Caucasian	2625 (86.0)	742 (91.4)
Non Caucasian	429 (14.0)	63 (8.6)
Work		
Employed/student	2043 (66.9)	587 (72.6)
Unemployed/retired/ disability	1011 (33.1)	222 (22.4)
Age		
Mean (SD)	46.4 (13.7)	39.9 (16.8)
Median	46	43
Moderate risk/problem gamblers (PGSI ≥ 5)[a]	116 (3.8)	29 (4.0)
Gambling intensity		
Mean monthly net win/loss (SD)	$CAN113.3 (250.1)	$CAN162.3 (594.9)
Median monthly net win/loss	$CAN36	$35CAN
Different forms of gambling played (median)	3	2
Play EGMs 2 3 times monthly or more (%)	5.5	4.8
Play casino games 2 3 times monthly or more (%)	1.5	2.6

[a]Scored based on revised rules [36,37]. SD = standard deviation; PGSI = Problem Gambling Severity Index; EGM = electronic gaming machines.

RESULTS

Differences in study samples

Table 1 compares the demographic characteristics of the LLLP and QLS samples. The most notable differences in the samples were age and marital status. The LLLP sample was on average 6 years younger and had a much higher proportion of single individuals. The two samples were very similar in terms of gambling characteristics.

Optimal cut offs determined from cross sectional data

The results of the receiver operating characteristic (ROC) analysis using the cross sectional (time 1 only) data are shown in Table 2. The optimal cut offs for frequency, expen diture and proportion of income spent on gambling were similar in the LLLP and QLS samples. The overall strength of prediction was better in the LLLP sample. The strength of prediction for our original low risk limits, the Quilty *et al.* study (also conducted on Canadian gamblers) and the LLLP samples fell in the moderate accuracy range. The optimal cut offs from the LLLP and QLS are notably higher than the cut offs derived from our original work. For exam ple, the low risk limits for frequency and percentage of in come were two times higher in the LLLP and QLS studies compared to the original limits derived from a large cross sectional national survey. The limits were also substantially higher than those reported by Quilty and colleagues [13].

Optimal cut offs determined from longitudinal data

The optimal limits were re calculated using the longitudi nal data from the LLLP and QLS. The risk curves for each gambling parameter are shown in Fig. 1. The overall shape of the dose response relationship for each parameter is similar in the LLLP and QLS samples. The amplitude of

Table 2 Performance of optimal cut points: cross sectional derived limits.

	Original low risk cut-offs[a]	*Community and clinical sample (n = 503)*[b]	*QLS*	*LLLP*
Frequency				
AUC	0.81	0.86	0.69	0.80
Optimal cut off	2 3/month	Once/month	7/month	6 times/month
Sensitivity/specificity	0.88/0.59	0.91/0.99	0.69/0.71	0.64 / 0.85
Dollars spent				
AUC	0.81	0.82	0.67	0.82
Optimal cut off	$CAN501 1000/year[c]	$CAN240.5/month	$85CAN/month	$CAN108/month
Sensitivity/specificity % gross income	0.78/0.70	0.83/0.78	0 58/0.75	0.73/0.80
AUC	0.79		0.66	0.81
Optimal cut off	1%		20.7%	20.1%
Sensitivity/specificity	0.74/0.74		0 58/0.77	0.72/0.79

[a]Currie *et al.*; [b]Quilty *et al.*; [c]equates to CAN$42 83 per month. AUC = area under the curve; QLS = Quinte Longitudinal Study; LLLP = Leisure, Lifestyle and Lifecycle Project.

the risk curve for percentage of income is noticeably higher for the QLS sample. The proportion of the QLS sample reporting harm was higher than the LLLP sample at the same level of gambling participation. The opposite trend is evident for frequency of gambling the LLLP sample shows higher proportions of individuals reporting harm than the QLS sample at the same level of gambling fre quency. For all three risk curves, the change in slope occurs at approximately the same point for each sample. For ex ample, the risk of experiencing harm increases visibly for both LLLP and QLS gamblers at the same point along the continuum of percentage of income spent on gambling.

Table 3 identifies the actual cut offs that optimally pre dict future harm from gambling based on the ROC and sensitivity specificity analyses. Compared to the cross sectional results in Table 2, the strength of prediction is lower when time 1 gambling behaviour is used to predict harm at time 2. All the AUCs reflected low predictive accu racy. After ensuring that specificity values are at least 0.70, the optimal limits for frequency diverge in the LLLP and QLS data sets (six times per month versus 10 times per month) and percentage of income (2 versus 1.4%). The op timal limits for expenditure per month are similar in both data sets.

Estimating risk of future harm when low risk limits are exceeded

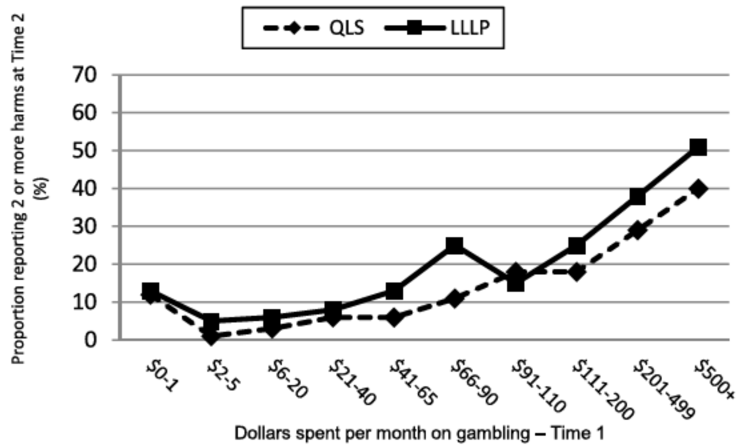
The mid point between the QLS and LLLP derived limits (frequency 8 times per month; expenditure $75CAN per month and percentage of income spent on gam bling 1.7%) was used as the cut off in the logistic re gression models for estimating the odds of experiencing future harm (shown in Table 4). Gambling above each of the low risk gambling limits predicted harm indepen dently at time 2 in both the QLS and LLLP for all parameters except percentage of income in the QLS data set, which was borderline significant. The overall strength of prediction was higher in the LLLP (R^2 0.17) than the QLS (R^2 0.11). Models were also created to assess the future risk associated with exceeding any of the low risk gambling limits. In the LLLP, 40% of gamblers exceeded at least one of the limits at time 1 and 7% exceeded all three limits. Gamblers who exceeded at least one limit at time 1 were 4.4 times more likely to report harm at time 2 [95% confidence interval (CI) 2.9 6.6; R^2 0.11]. In the QLS, 41% of gamblers exceeded at least one of the limits at time 1 and 11% exceeded all three limits. Exceeding any low risk limit at time 1 increased the risk of harm at time 2 by a factor of 3.7 (95% CI 2.9 4.7; R^2 0.08).

DISCUSSION

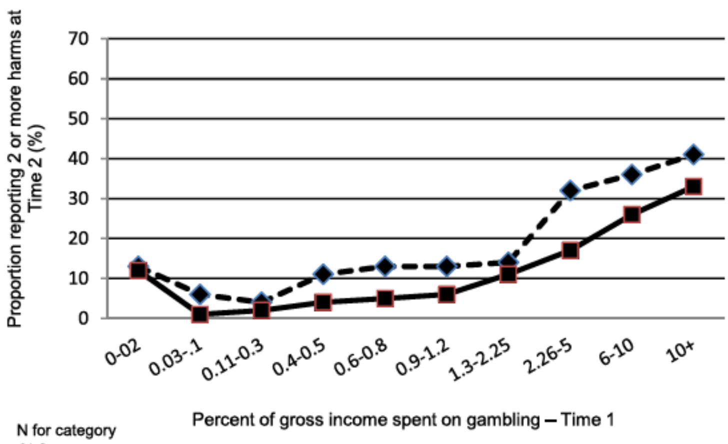
Low risk limits derived from longitudinal data

The main purpose of this study was to derive a new set of low risk cut offs for gambling using longitudinal data col lected in two similar but independently collected samples. The relationship between gambling intensity and risk of fu ture harm was remarkably similar in both studies. Based on the results from both samples the optimal low risk limit for expenditure is approximately $75CAN per month, for percentage of household income is approximately 1.7% and for frequency is eight times per month. Each of the low risk limits predicted future harm independently, with odds ratios ranging from 1.5 to 3.6. Gamblers who exceed any low risk limit are four times more likely to experience future harm.

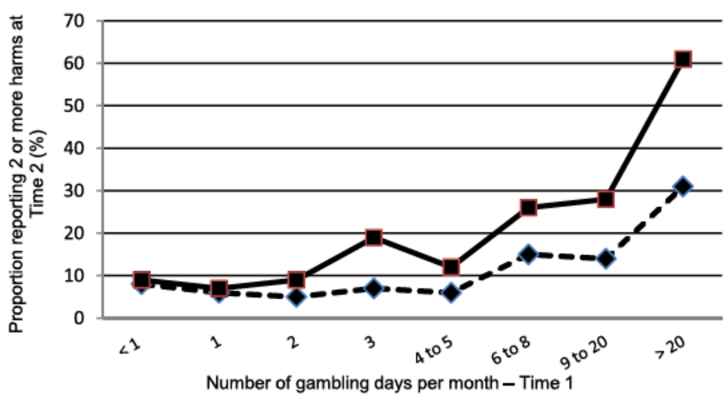
In contrast to previous risk curve analysis for gam bling, the shape of the dose response relationship was distinctly J shaped for both samples. The J shaped curve



N for category										
QLS	681	94	453	404	325	223	108	293	336	136
LLLP	45	107	180	104	86	53	34	80	66	47



N for category										
QLS	679	92	262	234	281	248	321	400	279	257
LLLP	39	108	141	74	62	63	91	77	44	66



N for category								
QLS	48	90	232	320	606	635	809	313
LLLP	146	128	143	113	114	66	54	41

Figure 1 Risk curves showing the relationship between measures of gambling intensity at time 1 and the proportion of gamblers experiencing two or more harms at time 2 in the Quinte Longitudinal Study (QLS) and Leisure, Lifestyle and Lifecycle Project (LLLP) samples. [Colour figure can be viewed at wileyonlinelibrary.com]

has been a consistent finding of population research relating daily alcohol consumption to all cause mortality. Does low level gambling provide protective benefits from harm similar to low level drinking? It is difficult to draw any conclusions without further replication with other data sets. Furthermore, unlike alcohol research studies, we did not include gambling abstainers. At present, the risk curve suggests low level gamblers (i.e. spending less than $40CAN in a typical month) experience less harm than very low level gamblers (spending less than $1CAN per month), although the degree of protection is relatively small.

Table 3 Performance of optimal cut points: longitudinal derived limits.

	QLS	*LLLP*
Frequency		
AUC (95% CI)	0.66 (0.63 0.70)	0.69 (0.63 0.74)
Optimal cut off	10 times/month	6 times/month
Sensitivity/specificity	0.49/0.70	0.45/0.85
Dollars spent		
AUC (95% CI)	0.67 (0.63 0.70)	0.73 (0.67 0.78)
Optimal cut off	$86CAN/month	$65CAN/month
Sensitivity/specificity	0.64/0.71	0.68/0.71
% gross income		
AUC (95% CI)	0.66 (0.63 0.69)	0.74 (0.69 0.79)
Optimal cut off	2%	10.4%
Sensitivity/specificity	0.72/0.70	0.66/0.73

AUC = area under the curve; CI = confidence interval; QLS = Quinte Longitudinal Study; LLLP = Leisure, Lifestyle and Lifecycle Project.

Differences in low risk limits when derived from cross sectional versus longitudinal data

Compared to the low risk limits derived from cross sectional data, the overall strength of prediction is lower when longitudinal data are used. One notable difference that could account for the drop in accuracy is the introduction of additional sources of variance. Using cross sectional data, a significant source of variance is measurement error associated with the dependent and independent variables. With longitudinal data, we introduce a new source of error the natural instability of gambling behaviour and associated harm. Both gambling behaviours and level of gambling problems are known to fluctuate over time without intervention [9,29]. This may account for the reduction in AUC and sensitivity/specificity values. We also acknowledge that harms appearing at time 2 may be due to changes in gambling behaviour that occurred after the time 1 assessment. With the interval between assessments being 12 and 19 months, there is no way to link time 2 harms definitively to the earlier assessment.

The optimal limits were higher when derived from longitudinal data. Several reasons are possible. One plausible explanation is that the level of gambling expenditure has to be significantly higher to have an enduring harmful impact a year later compared to the level of expenditure needed to have an immediate impact. The deliberate inclusion of a high proportion of at risk gamblers who have a higher level of gambling expenditure could also explain the more liberal limits. We also modified the statistical criteria for establishing the optimal cut off, giving more weight to the specificity value to lessen the false positive rate. The resulting limits were higher than previous studies. Another contributing factor is probably the improvements made in the assessment of gambling in more recent population studies. Gambling expenditure was assessed for each game type in the QLS and LLLP, whereas a singular question for all gambling expenditure was asked in the national survey data that was used to derive the original low risk limits. This latter approach has been shown to underestimate actual gambling expenditure [30]. In addition, a large sample of low intensity gamblers were excluded from answering the PGSI harm questions because of a controversial skipping rule employed in the national survey [31]. The overall similarity in both the shape of the risk curves and optimal low risk limits suggests that the present longitudinal findings may be more accurate for most gamblers.

Predicting future harm from low risk limits

The weak predictive power was also evident in the regression models. Exceeding the low risk limits at time 1 accounted for less than 20% of the variance in self reported harm at time 2. Although low, the proportion of variance explained is comparable to other population based studies predicting harm from gambling behaviour [11,21,32]. Furthermore, the fact that two independent studies produced similar low risk limits and odds ratios strengthens the validity of the findings. The QLS and LLLP samples differed in size and geographic representation; however, the gambling profile of participants was comparable. In terms of other sources of variance, theoretical models of aetiology propose that many factors influence whether an individual will experience harm from their gambling habits. In the multivariate model of aetiology developed from the LLLP

Table 4 Results of logistic regression: odds of experiencing future harm (time 2) in gamblers who exceed the low risk cut offs at time 1.

	QLS			*LLLP*		
Predictor	*OR*	*95% CI*	*P*	*OR*	*95% CI*	*P*
Gamble more than 8 times a month	1.7	1.3 2.2	0.000	2.3	1.3 3.8	0.003
Spend more than $75CAN /month	2.7	1.9 3.7	0.000	1.9	1.1 3.3	0.031
Spend more than 1.7% income on gambling	1.4	1.0 2.0	0.057	3.1	2.0 5.0	0.000
Model R square	0.11			0.17		

CI = confidence interval; OR = odds ratio; QLS = Quinte Longitudinal Study; LLLP = Leisure, Lifestyle and Lifecycle Project.

and QLS data sets, negative changes in personal circum stances (e.g. increase in stressful life events) in one time period led to both increased gambling behaviour and gambling problems in the subsequent period [7,8]. However, the personality trait impulsivity and mental health problems (depression and anxiety) predicted future gambling problems independently of a change in gambling involvement. It will be important for future research to examine how these characteristics interact with the low risk limits. Similar to the low risk drinking limits, it may be necessary to set additional guidelines and cautionary statements for more vulnerable populations.

Predicting future harm from current behaviour is gen erally more difficult, but the method has more external va lidity. Although cross sectional analysis leads to more robust results, the approach suffers from the inherent bias that both the exposure and outcome variables are mea sured at the same point in time. The study is important be cause it provides the first direct validation of the predictive power of low risk gambling limits. The findings are also an important extension of the theoretical model of the etiology of problem gambling developed from the QLS/LLLP studies. The present data demonstrate that the intensity of gam bling activity as measured by frequency and expenditure is predictive of general indicators of harm in addition to problem gambling. The study also suggests that safe levels of gambling can be defined, a finding that has implications for public health models aimed at prevention.

Limitations

Subtle differences in the gambling participation questions across surveys required us to recode data on frequency and expenditures to ensure that the dose response curves were comparable. To construct a meaningful estimate of gambling expenditure that could be analysed, it was neces sary to re code self reported profits as zero. The reliability and validity of self reported gambling expenditure is only moderate, and an ongoing limitation of the present method used to construct low risk limits [33]. Nevertheless, the question wordings and data cleaning procedures (e.g. converting wins to zero) used in the present analysis are known to produce the best match with diary amounts and actual jurisdictional gambling revenue [30]. Data availability in both samples restricted our analysis to only three dimensions of playing intensity (frequency, expendi ture and portion of income. Other research teams have ex plored additional quantitative dimensions of gambling behaviour, including duration of play [12] and number of different gambling formats [14]. Percentage of income spent on gambling is arguably the best dimension of gam bling behaviour, because it puts losses into the context of the individual's financial means. Nonetheless, the wide va riety of gambling types and wagering methods has proved a serious barrier to research on this topic. Unlike the stan dard alcohol drink, there is no meaningful standard unit of gambling. The interval between wager and outcome varies considerably across gambling formats from a matter of seconds (e.g. slot machines) to days (e.g. lottery). Hence, the degree of inherent risk can vary substantially across gambling formats, even at the same level of gambling in tensity. The development of game specific limits, the ap proach taken by a recent German study for electronic gaming machines (EGMs) and poker [14], may be the only way to resolve this limitation in gambling research.

Despite the low accuracy of prediction there remains potential value of low risk limits as a prevention or public education tool. Low risk guidelines can serve as quantita tive reference points to inform gamblers of the relative risk if they choose to exceed them. Most gamblers who attempt to control their gambling actively do so by setting time and monetary limits [34]. Like the low risk drinking guidelines, not all gamblers who exceed the limits will ex perience harm. Conversely, staying below the limits does not provide complete protection from future harm. It will be important for any public health messaging to incorpo rate such limitations to avoid giving gamblers a false sense of security. Approximately 60% of gamblers in the QLS and LLLP studies stayed below the low risk limits. By comparison, approximately 79% of Canadians who consume alcohol stay within the low risk drinking limits [35]. The limits proposed in the current study require further validation with other longitudinal studies to determine if (1) the overall strength of prediction can be improved and (2) the proposed cut offs predict future harm in a novel data set.

Declaration of interests

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References

1. Afifi T. O., Cox B. J., Martens P. J., Sareen J., Enns M. W. Demo graphic and social variables associated with problem gambling among men and women in Canada. *Psychiatry Res* 2010; **178**: 395 400.
2. Yau Y. H. C., Potenza M. N. Gambling disorder and other behavioral addictions: recognition and treatment. *Harv Rev Psychiatry* 2015; **23**: 134 46.
3. Williams R. J., Volberg R., Stevens R. A. The population Prevalence of Problem Gambling: Methodological Influences, Standardized Rates, Jurisdictional Differences, and World wide Trends. In: *Report prepared for the Ontario Problem Gambling Research Centre and the Ontario Ministry of Health and Long Term Care.* Alberta: University of Lethbridge; 2012 Available at: https://www.uleth.ca/dspace/handle/10133/3068 (accessed 1 March 2017) (Archived at http://www.webcitation.org/6H8XsuQ8n on 8 May 2015).
4. Welte J. W., Barnes G. M., Tidwell M. C., Hoffman J. H., Wieczorek W. F. Gambling and problem gambling in the United States: changes between 1999 and 2013. *J Gambl Stud* 2015; **31**: 695 715.
5. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders,* 5th edn. Washington, DC: American Psychiatric Association; 2013.
6. Hodgins D. C., Stea J., Grant J. E. Gambling disorders. *Lancet* 2011; **378**: 1874 84.
7. el Guebaly N., Casey D., Currie S. R., Hodgins D. C., Schopflocher D., Smith G. J. *et al.* The Leisure, Lifestyle, & Lifecycle Project (LLLP): A Longitudinal Study of Gambling in Alberta. Final Report for the Alberta Gambling Research Institute. Calgary, Alberta: Alberta Gambling Research Institute. 2015. Available at: http://dspace.ucalgary.ca/bitstream/1880/50377/1/LLLP Final Report Feb21 2015 V4.pdf (accessed 1 March 2017) (Archived at http://www.webcitation.org/6rlB4iSIB on 6 July 2017).
8. Williams R. J., Hann R. G., Schopflocher D., West B., McLaughlin P., White N. *et al.* Quinte Longitudinal Study of Gambling and Problem Gambling. Report prepared for the Ontario Problem Gambling Research Centre. Guelph, Ontario. Guelph, Ontario: Ontario Problem Gambling Research Centre. 2015. Available at: https://www.uleth.ca/dspace/handle/10133/3641 (accessed 1 March 2017) (Archived at http://www.webcitation.org/6rlB77cEP on 6 July 2017).
9. Billi R., Stone C. A., Marden P., Yeung K. *The Victorian Gambling Study: A Longitudinal Study of Gambling and Health in Victoria, 2008 2012.* Victoria, Australia: Victorian Respon sible Gambling Foundation; 2014 Available at: http://www.responsiblegambling.vic.gov.au/ data/assets/pdf file/0008/10016/A LONGITUDINAL STUDY OF GAMBLING AND HEALTH IN VICTORIA 20082012.pdf (accessed 1 March 2017) (Archived at http://www.webcitation.org/6b1SfoUPD on 24 August 2015).
10. Froberg F., Rosendahl I. K., Abbott M. W., Romild U., Tengstrom A., Hallqvist J. The incidence of problem gam bling in a representative cohort of Swedish female and male 16 24 year olds by socio demographic characteristics, in comparison with 25 44 year olds. *J Gambl Stud* 2015; **31**: 621 41.
11. Currie S. R., Hodgins D. C., Wang J., el Guebaly N., Wynne H., Chen S. Risk of harm from gambling in the general population as a function of level of participation in gambling activities. *Addiction* 2006; **101**: 570 80.
12. Weinstock J., Ledgerwood D. M., Petry N. M. Association be tween posttreatment gambling behavior and harm in pathological gamblers. *Psychol Addict Behav* 2007; **21**: 185 93.
13. Quilty L. C., vila Murati D., Bagby R. M. Identifying indicators of harmful and problem gambling in a Canadian sample through receiver operating characteristic analysis. *Psychol Addict Behav* 2014; **28**: 229 37.
14. Brosowski T., Hayer T., Meyer G., Rumpf H., John U., Bischof A. *et al.* Thresholds of probable problematic gambling involve ment for the German population: results of the pathological gambling and epidemiology (PAGE) study. *Psychol Addict Behav* 2015; **29**: 374 804.
15. Room R., Babor T., Rehm J. Alcohol and public health. *Lancet* 2005; **365**: 519 30.
16. Room R., Bondy S. J., Ferris J. The risk of harm to oneself from drinking, Canada 1989. *Addiction* 1995; **90**: 499 513.
17. Di Castelnuovo A., Costanzo S., Bagnardi V., Donati M. B., Iacoviello L., de Gaetano G. Alcohol dosing and total mortality in men and women: an updated meta analysis of 34 prospective studies. *Arch Intern Med* 2006; **166**: 2437 45.
18. Rehm J., Room R., Graham K., Monteiro M., Gmel G., Sempos C. T. The relationship of average volume of alcohol consump tion and patterns of drinking to burden of disease: an overview. *Addiction* 2015; **98**: 1209 28.
19. Stockwell T., Butt P., Beirness D., Gliksman L., Paradis C. The basis for Canada's new low risk drinking guidelines: a relative risk approach to estimating hazardous levels and patterns of alcohol use. *Drug Alcohol Rev* 2012; **31**: 126 34.
20. Langham E., Thorne H., Browne M., Donaldson P., Rose J., Rockloff M. Understanding gambling related harm: a pro posed definition, conceptual framework, and taxonomy of harms. *BMC Public Health* 2016; **16**: 80.
21. Currie S. R., Hodgins D. C., Wang J., el Guebaly N., Wynne H., Miller N. V. Replication of low risk gambling limits using Canadian provincial gambling prevalence data. *J Gambl Stud* 2008; **24**: 321 35.
22. el Guebaly N., Casey D., Hodgins D. C., Smith G., Williams R. J., Schopflocher D. P. *et al.* Designing a longitudinal cohort study of gambling in Alberta: rationale, methods, and challenges. *J Gambl Stud* 2008; **4**: 479 504.
23. Currie S. R., Hodgins D. C., Casey D., el Guebaly N., Smith G., Williams R. J. *et al.* Examining the predictive validity of low risk gambling limits with longitudinal data. *Addiction* 2011; **107**: 400 6.
24. Ferris J., Wynne H. J. *The Canadian Problem Gambling Index Final Report*. Canadian Centre on Substance Abuse: Ottawa, ON; 2001. Available at: http://www.ccgr.ca/en/projects/re sources/CPGI Final Report English.pdf (accessed 1 March 2017) (Archived at http://www.webcitation.org/6rlL2GZYr on 6 July 2017).
25. Currie S. R., Miller N. V., Hodgins D. C., Wang J. Defining a threshold of harm from gambling for population health surveillance research. *Int Gambl Stud* 2008; **9**: 19 38.

26. DeLong E. R., DeLong D. M., Clarke Pearson D. L. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988; **44**: 837 45.
27. Swets J. A., Dawes R. M., Monahan J. Psychological science can improve diagnostic decisions. *Psychol Sci Public Interest* 2001; **1**: 1 26.
28. Ruopp M. D., Perkins N. J., Whitcomb B. W., Schisterman E. F. Youden index and optimal cut point estimated from observations affected by a lower limit of detection. *Biom J* 2008; **50**: 419 30.
29. Hodgins D. C., El Guebaly N. Natural and treatment assisted recovery from gambling problems: a comparison of resolved and active gamblers. *Addiction* 2000; **95**: 777 89.
30. Williams R. J., Volberg R. A., Stevens R. M. G., Williams L. A., Arthur J. N. The Definition, Dimensionalization, and Assessment of Gambling Participation. *Report prepared for the Canadian Consortium for Gambling Research* Lethbridge, Alberta: University of Lethbridge. University of Lethbridge, 2016. Available at: http://www.ccgr.ca/en/projects/gambling participation instrument.aspx (accessed 1 March 2017) (Archived at http://www.webcitation.org/6rlBNk9jF on 6 July 2017).
31. Cunningham J. A. Risk curves: gambling with data. *Addiction* 2006; **101**: 1214 5.
32. Markham F., Young M., Doran B. The relationship between player losses and gambling related harm: evidence from nationally representative cross sectional surveys in four countries. *Addiction* 2015; **111**: 320 30.
33. Wood R. T., Williams R. J. 'How much money do you spend on gambling?': the comparative validity of question wordings used to assess gambling expenditure. *Int J Soc Res Methodol* 2007; **10**: 63 77.
34. Moore S. M., Thomas A. C., Kyrios M., Bates G. The self regulation of gambling. *J Gambl Stud* 2012; **28**: 405 20.
35. Statistics Canada *Canadian Tobacco, Alcohol and Drugs Survey (CTADS) summary of results for 2013*. Statistics Canada: Ottawa, Ontario; 2015 Available at: http://healthycanadians.gcca/science research sciences recherches/data donnees/ctads ectad/summary sommaire 2013 eng.php? ga=1.168653857.1232452602.1467742329 (accessed 1 March 2017) (Archived at http://www.webcitation.org/6rlBQAUUU on 6 July 2017).
36. Currie S. R., Hodgins D. C., Casey D. Validity of the problem gambling severity index interpretive categories. *J Gambl Stud* 2012; **29**: 311 27.
37. Williams R. J., Volberg R. Classification accuracy of four problem gambling assessment instruments. *Int Gambl Stud* 2014; **14**: 15 28.

