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The relationship between player losses and gambling-related harm: evidence from nationally representative cross-sectional surveys in four countries

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ABSTRACT

Background and Aims Flaws in previous studies mean that findings of J-shaped risk curves for gambling should be disregarded. The current study aims to estimate the shape of risk curves for gambling losses and risk of gambling-related harm (a) for total gambling losses and (b) disaggregated by gambling activity. **Design** Four cross-sectional surveys. **Setting** Nationally representative surveys of adults in Australia (1999), Canada (2000), Finland (2011) and Norway (2002). **Participants** A total of 10 632 Australian adults, 3120 Canadian adults, 4484 people aged 15–74 years in Finland and 5235 people aged 15–74 years in Norway. **Measurements** Problem gambling risk was measured using the modified South Oaks Gambling Screen, the NORC DSM Screen for Gambling Problems and the Problem Gambling Severity Index. **Findings** Risk curves for total gambling losses were estimated to be r-shaped in Australia {β losses = 4.7 [95% confidence interval (CI) = 3.8, 6.5], β losses^{2} = –7.6 (95% CI = –17.5, –4.5)}, Canada [β losses = 2.0 (95% CI = 1.3, 3.9), β losses^{2} = –3.9 (95% CI = –15.4, –2.2)] and Finland [β losses = 3.6 (95% CI = 2.5, 7.5), β losses^{2} = –4.4 (95% CI = –34.9, –2.4)] and linear in Norway [β losses = 1.6 (95% CI = 0.6, 3.1), β losses^{2} = –2.6 (95% CI = –12.6, 1.4)]. Risk curves for different gambling activities showed either linear, r-shaped or non-significant relationships. **Conclusions** Player loss–risk curves for total gambling losses and for different gambling activities are likely to be linear or r-shaped. For total losses and electronic gaming machines, there is no evidence of a threshold below which increasing losses does not increase the risk of harm.

Keywords dose-response, Electronic gaming machines, gambling, gambling losses, gambling expenditure, gambling-related harm, public health, problem gambling, risk curves.

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INTRODUCTION

The social and health impacts of gambling result primarily from gamblers losing money [1]. Although problem gambling is conceptualized frequently as a behavioural addiction [2], because the loss of money is the cause of many of the harms associated with gambling, losses are therefore worthy of investigation in their own right. However, the relationships between money lost gambling and gambling-related harms have rarely been the specific subject of sustained investigation. The only gambling-related harm to have received substantial scrutiny in relation to money lost on gambling is problem gambling risk, as measured by problem gambling screens and their constituent items in numerous problem gambling prevalence studies (e.g. [3–5]). Money lost should be of particular interest to policymakers and scholars, because loss statistics that are collected routinely by governments at the jurisdictional and venue levels could potentially play an important role in regulation.

One line of research into monetary losses from gambling that has received intermittent scholarly attention has been the establishment of safe consumption guidelines. Taking their cue from alcohol consumption guidelines, a handful of studies have sought to identify ‘safe’ levels of gambling consumption [6–10]. Using a variety of methods, these studies have sought to define a threshold point for gambling consumption which maximizes the differentiation between problem and non-problem gamblers. In a much-cited Canadian national study [6] and its replication in three Canadian provinces [7], Currie and colleagues reported the existence of J-shaped risk curves, analogous to those long reported for the effect of alcohol consumption on coronary heart disease (e.g. [11]). On this basis, receiver operating curve (ROC) analyses found low-risk gambling thresholds at $500–1000/year in Canada [6], and $1020/year, $400/year and $132–600/year in Alberta, Ontario and British Columbia, respectively [7]. Weinstock *et al*. [8] performed a similar analysis on a sample of 178 post-treatment gamblers in the United States, finding that a threshold of ≤1.9% of monthly income spent gambling was the best cut-point for predicting problem-gambling symptoms. Stinchfield & Winters [9] and Rockloff [10] performed similar analyses using gambling frequency as the predictor variable, both finding that time spent gambling was useful for discriminating problem from non-problem gamblers. These authors did not differentiate between consumption of different gambling activities.

Underpinning these studies is an understanding that the relationship between gambling-related harm and gambling consumption is J-shaped. Indeed, the existence of J-shaped consumption–risk curves is assumed in much literature in the field of gambling studies and is crucial to the 'responsible gambling' approach to regulation. For example, in their influential Reno model, Blaszczynski *et al*. [12] wrote that the first of six 'fundamental assumptions' contained within the responsible gambling framework is that 'safe levels of gambling participation are possible'. Co-author Howard Shaffer [13] was more explicit in a later publication, where he claimed that '[g]ambling, like drinking alcohol, displays a "dose–response" association that reflects hormesis as an underlying process'. If the consumption–risk relationship is not J-shaped, then there can be little scientific underpinning to safe consumption limits: a linear relationship, for example, would imply that all consumption increases risk of harm. As Midanik *et al*. [14] discuss in the context of alcohol, without a clear threshold below which an individual is at zero risk of harm, guidelines need to consider what amount of absolute risk can be tolerated.

The shape of the relationship between money lost gambling and gambling-related harm has been the subject of remarkably little research. Of the studies cited above, only those led by Currie [6,7] sought to describe empirically the shape of the consumption–risk curve. Currie and colleagues found that the 'nature of the relationship between risk level and gambling behaviour is best described as J-shaped' [6]. Unfortunately, this result must be ascribed to a flawed interpretation of an artefact resulting from the survey instrument. The Canadian Community Health Survey 1.2 (CCHS) analysed in that paper collected player loss data using ordinal brackets of increasing magnitude, rather than in exact dollars. These brackets were treated as though they were of equal magnitude in the published plots, reproduced in Fig. 1a. However, a recoding of these brackets using their mid-points and dropping the final open-ended bracket is strongly suggestive of a linear relationship between gambling losses and harm (see Fig. 1b). A similar pattern can be detected in the replication study, although the data are noisier (see Fig. 1c,d). The

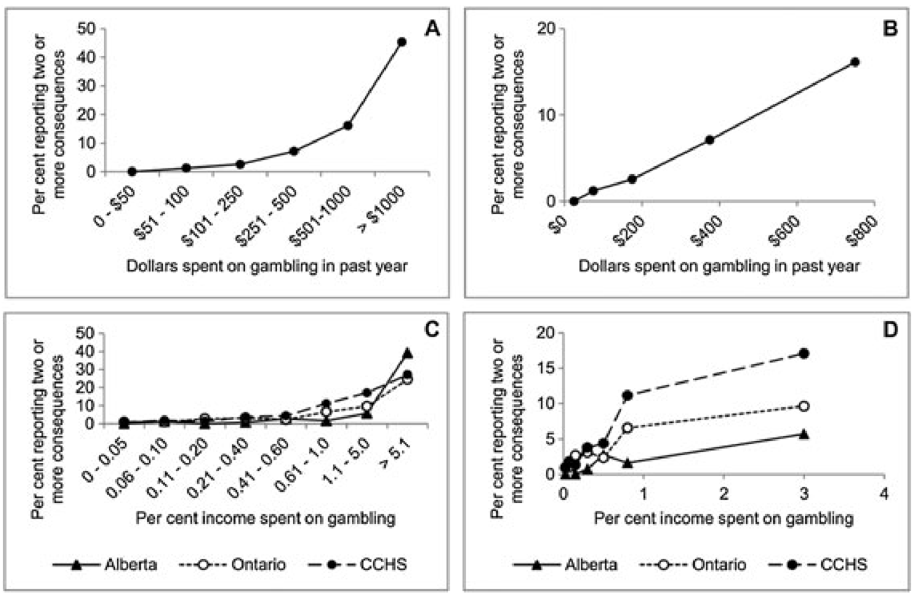

Figure 1 When bracketed player loss data are used, the shape of the risk curve depends on how brackets are treated. Panels (a) and (b) show the dollars spent on all forms of gambling in the past year by the percentage of respondents reporting two or more negative consequences from gambling. Panels (c) and (d) show the percentage of household income spent on all forms of gambling by the percentage of respondents reporting two or more negative consequences from gambling. Panels (a) and (c) use the original, non-equal width brackets while panels (b) and (d) use mid-point coding and drop the final, unbounded bracket. Data were digitized from Fig. 1 in Currie *et al*. [6] and Fig. 2 in Currie *et al*. [7]. CCHS = Canadian Community Health Survey

absence of any apparent J-shape in the corrected curves makes the identification of safe gambling thresholds highly problematic.

A further limitation of published risk curves is that they are presented for total gambling losses only. Many studies have shown that there is great variation in the associations between harm and participation in different gambling activities (e.g. [15,16]), with recent prospective studies showing that some gambling activities predict the onset of future harms more strongly than others [17–19]. It is likely, therefore, that consumption–risk curves vary between gambling activities.

The purpose of the current study is to identify the shape of the association between monetary gambling losses and problem gambling risk for different gambling activities. To do so, we perform a secondary analysis of four nationally representative cross-sectional surveys from Australia, Canada, Finland and Norway. Using bootstrapped local polynomial regression, multiple linear regression and mixed effects linear models we: (1) estimate the shape of gambling loss–problem gambling risk curves for total gambling losses; and (2) estimate the shape of gambling loss–problem gambling risk curves disaggregated by gambling activity.

METHODS

Data

Player loss data are typically subject to several shortcomings. In particular, non-gambling-specific household surveys under-report gambling losses dramatically [1], although gambling-specific surveys also encounter under-reporting (e.g. [20]). While improvements to sample design and question format have mitigated these problems [21], it is plausible that survey instruments will impact upon the results. Therefore, we have taken a replication approach to improve confidence in our findings. By using multiple data sets collected with different survey instruments, we hope to determine if our findings are robust across differently collected samples.

Secondary data sets were sought for Australia, Canada, Denmark, Finland, New Zealand, Norway, the United States, the United Kingdom, Singapore and Sweden. Using a list of prevalence studies [22], we searched for data sets which: were nationally representative; were from a country reporting high levels of gambling losses; included a validated screening test for problem gambling; included questions about gambling expenditure in which losses were recorded as a continuous variable rather than a bracketed ordinal variable; and in which questions about gambling losses were disaggregated by gambling activity. Four studies were identified as suitable using this protocol and were available for re-analysis.

Where appropriate, questions about losses were combined (e.g. questions about gambling losses on lottery tickets purchased online or in stores were combined). To minimize differences in units between jurisdictions and time-periods, player loss variables were converted to 2013 currency units using country-specific consumer price indices. These were then converted to US dollars per month using exchange rates adjusted for purchasing power parity for private consumption [23]. In all studies, socio-demographic questions elicited respondents' sex, age, employment status, education level, income and marital status.

The Australian National Gambling Survey was a nationally representative telephone interview survey of Australian adults, conducted in March and April 1999 [24]. The measure of gambling-related harm in this study was a problem gambling screen, the modified South Oaks Gambling Screen (SOGS-M). The SOGS-M reframes questions from the original SOGS [25] to enquire only about the last 12 months. SOGS-M was administered only to those who gambled at least 52 times per year or whose annual gambling losses reached AU$4000 in 1999. While 10 632 people responded to the survey (response rate = 47%), only the 1240 who completed SOGS-M were included in this study. A complex series of questions were used to elicit information from which losses were calculated. For example, respondents who gambled at racecourses were asked: 'Thinking of when you go to a racecourse, how much money do you usually take with you to bet on the races, including any additional money withdrawn or borrowed during your time at the races? And how much money do you usually have left when you leave the races?'. Responses were combined with questions on gambling frequency to estimate annual losses. In the present study the absolute value of losses was used to simplify estimates, following Welte *et al.* [3]. For a detailed account of the survey see Productivity Commission [15].

The Canadian National Validation Survey was a telephone interview survey of Canadian adults undertaken between February and April 2000, as part of the development of the Canadian Problem Gambling Index [26]. The survey included the Problem Gambling Severity Index (PGSI), a validated problem gambling screen [27]. Losses on individual gambling activities were estimated by asking, for example: 'How much money, not including winnings, do you spend on raffle or fundraising tickets in a typical month?'. All respondents were administered the PGSI. A total of 3120 completed responses were recorded.[1] For a detailed account of the survey see Ferris & Wynne [27,28].

[1]No information regarding response rate is currently available from published sources, the data documentation, the first author of the study or the data collection agency.

The Finnish Gambling Survey 2011 was a representative telephone interview survey of 4484 people on the Finnish population register aged 15–74 years, undertaken between October 2011 and January 2012 (response rate = 28%) [29]. The PGSI was administered to those who had participated in gambling in the past 12 months ($n = 3451$) and was used to measure gambling-related harm in the present study. For each activity for which respondents reported past 12-month gambling participation, respondents were asked questions such as: 'How much MONEY did you spend on the following in the past 30 days (in euros)? Please include all the money you used regardless of whether you lost or won'. For a detailed account of the survey see Castrén *et al.* [30].

The Gambling in Norway 2002 survey was a representative multi-modal survey of 5235 Norwegians aged 15–74 years, undertaken in 2012 (response rate = 55%). The last 12-month version of the NORC DSM Screen for Gambling Problems (NODS) was used to measure gambling-related harm, with the screen administered to all respondents who reported ever gambling. Life-time non-gamblers were assigned a score of zero. For more details regarding NODS, see Gerstein *et al.* [20]. For each activity for which respondents reported participation, respondents were asked questions such as: 'Approximately how much money have you gambled for on gambling machines in the last 30 days?'. For a detailed account of the survey see Lund [31].

The outcome variable used in all analyses was a validated problem gambling scale (SOGS, PGSI or NODS). These scales were treated as a continuous measure of the harm continuum, with increasing scores on the scale indicating elevated levels of harm.

Statistical analysis

Player loss–problem-gambling risk curves were visualised using loess, a locally weighted, non-parametric polynomial regression [32]. In order to reduce the influence of outliers and end-points and to communicate more effectively the variation in the data, an ordinary, non-parametric bootstrap was used to draw 1000 loess fits for each risk curve. The optimal span parameter for loess fits was selected for each bootstrap draw by minimizing Akaike's information criterion (AICc) [33]. A separate curve was drawn for total player losses and losses by gambling activity for each of the four surveys. y-Axes were adjusted to align the problem gambling scales using the standardized thresholds suggested by Williams & Volberg [34] for problem gambling: SOGS-M = 4; PGSI = 5; NODS = 3. To emphasize the range of player losses that includes the vast majority of respondents, risk curves were not plotted beyond $2000 US dollars per month, although loess fits included the full data range. For plots of the region between $0 and $250 US dollars, see the online Supporting information (Figs S1 and S2).

Regression analysis was used to identify the significance of curves identified in the bivariate analysis after adjusting for differential risk among population subgroups. Multiple linear regression was used with problem gambling screen scores as the outcome variable. The variables of interest, player loss on a gambling activity and the square of that value were both included as predictor variables. Covariates used to account for differential risk among demographic groups were: age (including a quadratic term); sex; education level; marital status; employment status; and income (including a quadratic term). Due to the presence of influential observations with large gambling losses, estimates were calculated using the ordinary, non-parametric bootstrap with 5000 replications and 95% confidence intervals approximated using the percentile method. While P-values were not generated from bootstrap estimates, beta coefficients are considered statistically significant at the 0.05 level if the 95% confidence interval does not contain zero.

A bootstrapped mixed-effects linear model with random intercepts and random slopes for the loss variables was also estimated for total gambling losses. Differences in activities across countries precluded their inclusion in mixed-effects models. This model pooled data from all four surveys, with the survey as the grouping variable, in order to increase the parsimony of the model and improve the precision of estimates.

Population weights were not used in the regression analyses, although their use did not appear to influence results substantively (see online Supporting information, Table S1). Curve shape can be inferred by interpreting the estimated coefficients in the linear regression analysis. A positive coefficient for the quadratic loss term implies a J-shaped curve, while a negative coefficient implies an r-shaped curve. Missing data were removed listwise, so sensitivity analyses were conducted to estimate the potential impact of missing data on results.

All analyses were conducted using R with the *boot* and *lme4* packages [35–37]. Human ethics approval was granted by the Human Research Ethics Committee of The Australian National University (protocol no. 2014/313).

RESULTS

Responses from 8884 individuals who completed the problem gambling screen across the four surveys are summarized by loss tercile in Table 1.

Visual inspection of loess curves for total gambling losses in Fig. 2 suggests a slightly r-shaped curve in all four surveys. As gambling losses mount, so too does the average risk as measured by the various problem gambling screens. There is no low-risk region of the curve where increasing

Table 1 Descriptive statistics of variables of interest, disaggregated by tercile of total gambling losses per month.

	Loss tercile 1 n = 2940			*Loss tercile 2 n = 2979*			*Loss tercile 3 n = 2965*		
Numerical variables	*mean*	*SD*	*n*	*mean*	*SD*	*n*	*mean*	*SD*	*n*
Problem gambling score[a]	0.03	0.13	2940	0.05	0.20	2979	0.24	0.51	2965
Losses (US$ 2013)	8	6	2940	31	10	2979	238	430	2965
Age	45	16	2932	47	15	2967	45	16	2944
Income (US$ 2013)	19 859	32 079	2417	34 093	37 155	2371	30 919	40 879	2300
Categorical variables	*n*	*%*		*n*	*%*		*n*	*%*	
Employment	2930			2970			2949		
Employed	1746	60%		1984	67%		1977	67%	
Not employed	1184	40%		986	33%		972	33%	
Education	2921			2956			2937		
School	1305	45%		1649	56%		1705	58%	
Post-school	1616	55%		1307	44%		1232	42%	
Survey	2940			2979			2965		
Australia 1999	214	7%		258	9%		756	25%	
Canada 2000	393	13%		716	24%		966	33%	
Finland 2011	1687	57%		972	33%		738	25%	
Norway 2002	646	22%		1033	35%		505	17%	

[a]Problem gambling score standardized so that 1.0 is equal to the problem gambling thresholds calculated by Williams & Volberg [34]: South Oaks Gambling Screen (SOGS)-M = 4; Problem Gambling Severity Index (PGSI) = 5; NORC DSM Screen for Gambling Problems (NODS) = 3. SD = standard deviation.

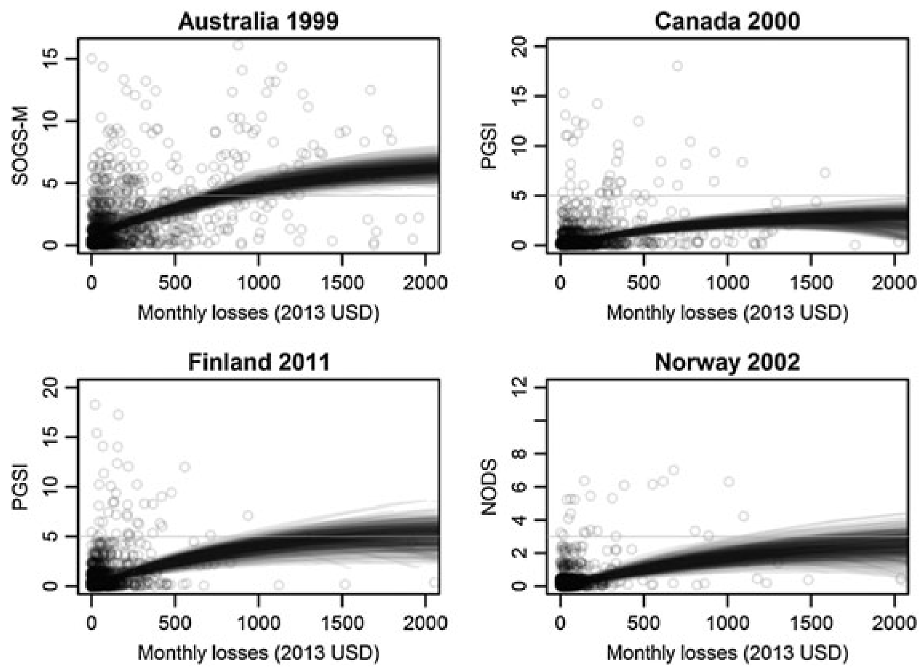

Figure 2 Bootstrapped risk curves for total gambling losses versus problem gambling risk. Horizontal lines represent the standardized problem gambling thresholds calculated by Williams & Volberg [34]: South Oaks Gambling Screen (SOGS)-M = 4; Problem Gambling Severity Index (PGSI) = 5; NORC DSM Screen for Gambling Problems (NODS) = 3. Losses are standardized to 2013 US dollars spent in previous 30 days. Each point represents a single respondent, jittered for display. Each line represents a single non-parametric bootstrapped loess fit, with span selected by Akaike's information criterion (AICc). Median spans (and 95% confidence intervals) were: 1.0 (0.4, 5.0), 1.0 (0.8, 5.0), 1.0 (0.6, 5.0) and 1.4 (0.6, 5.0)

gambling losses does not increase harm. A flattening of the risk gradient is evident in the Canadian data at a mean PGSI level of approximately 3.

The risk curves for individual gambling activities presented in Fig. 3 are diverse. For electronic gambling machines (EGMs) the risk curves all appear r-shaped, with particularly steep gradients in Australia and Norway and a truncated arc in Finland, where no respondent reported spending more than $320 US dollars per month. Lottery risk curves appear much flatter than those for EGMs, with

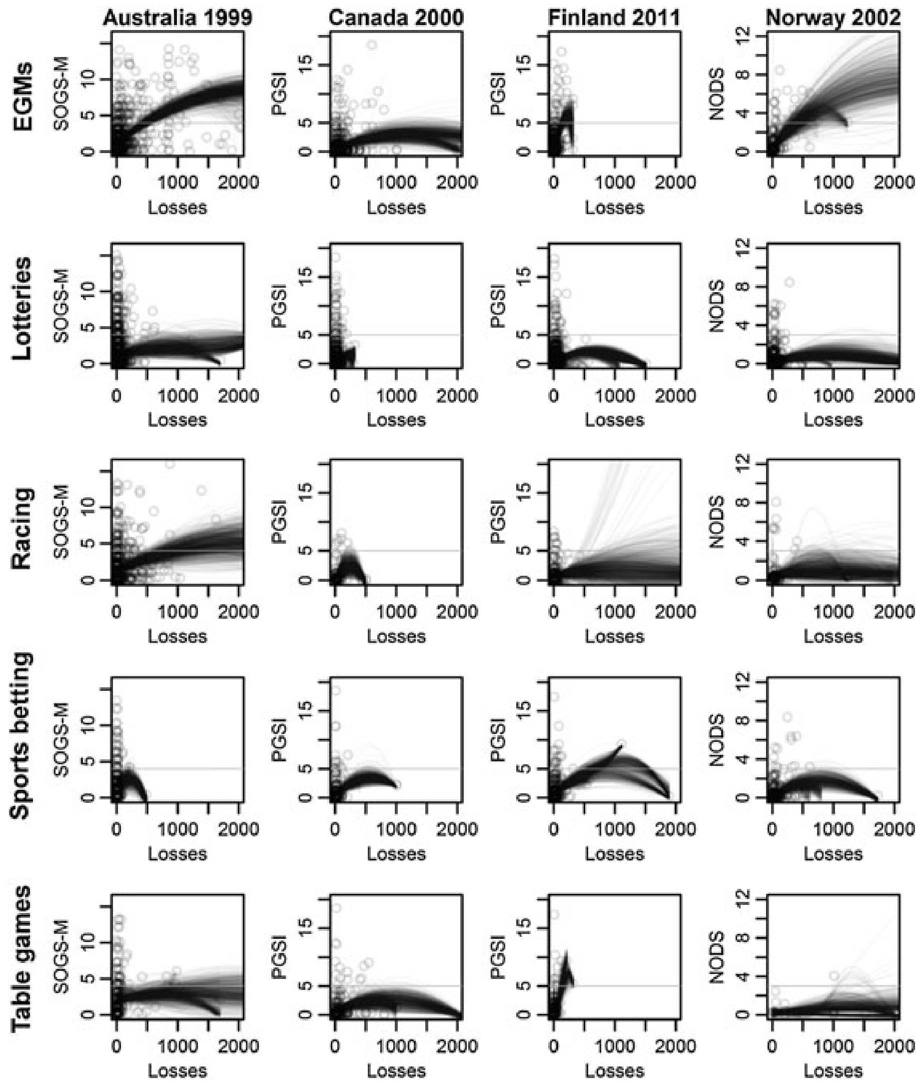

Figure 3 Bootstrapped risk curves for gambling losses versus problem gambling risk for five gambling activities. Horizontal lines represent the standardized problem gambling thresholds calculated by Williams & Volberg [34]: South Oaks Gambling Screen (SOGS)-M = 4; Problem Gambling Severity Index (PGSI) = 5; NORC DSM Screen for Gambling Problems (NODS) = 3. Losses are standardized to 2013 US dollars spent in previous 30 days. Each point represents a single respondent, jittered for display only. Each line represents a single non-parametric bootstrapped loess fit, with span selected by Akaike's information criterion (AICc). Median spans from left to right, top to bottom (and 95% confidence intervals) were electronic gambling machines (EGMs): 2.8 (0.9, 5.0), 1.0 (0.7, 5.0), 1.0 (0.5, 5.0), 1.2 (0.8, 5.0); lotteries: 2.5 (0.7, 5.0), 5.0 (0.8, 5.0), 1.7 (0.6, 5.0), 1.0 (0.7, 5.0); racing: 1.3 (0.7, 5.0), 5.0 (0.8, 5.0), 1.2 (0.6, 5.0), 2.4 (1.1, 5.0): sports betting: 1.5 (1.0, 5.0), 5.0 (1.1, 4.9), 1.3 (0.8, 5.0), 1.6 (1.0, 5.0); table games: 1.7 (0.6, 5.0), 5.0 (0.9, 5.0), 1.0 (0.6, 5.0), 2.4 (0.9, 5.0)

a generally linear appearance. Risk curves for racing varied in shape, with a steep, linear curve in Australia and flatter gradients in other countries. Risk curves for sports betting and table games were noisy and variable between surveys. Additional analysis using standard, non-bootstrap methods found similar results (online Supporting information, Figs S3 and S4).

The analyses reported in Table 2 largely confirmed these qualitative relationships. Significant negative quadratic loss coefficients were found for total gambling losses in Australia, Canada and Finland, indicating r-shaped curves, while a linear relationship was found for total gambling expenditure in Norway. Statistically significant r-shaped curves were observed for: EGM gambling in Australia, Canada and Norway; lotteries in Canada and Finland; and sports betting in Norway. Statistically significant linear relationships were observed for EGMs and sports betting in Finland and racing in Australia. The results were inconclusive as to whether or not an association is present for the 11 remaining risk curves. The only gambling products which may entail a J-shaped dose–response relationship were lotteries in Australia and racing in Finland, but estimates of these curves did not reach significance. Gambling losses predicted up to 25% of the

Table 2 Multiple linear regression and mixed effects linear model estimates of player loss–problem gambling risk curves by gambling activity.

		Australia 1999 (95% confidence interval)	*Canada 2000* (95% confidence interval)	*Finland 2011* (95% confidence interval)	*Norway 2002* (95% confidence interval)
Total	$10^3 \times \beta$ losses	**4.7 (3.8, 6.5)**	**2.0 (1.3, 3.9)**	**3.6 (2.5, 7.6)**	**1.6 (0.6, 3.1)**
	$10^7 \times \beta$ losses^2	**–7.6 (–17.5, –4.5)**	**–3.9 (–15.4, –2.2)**	**–4.4 (–34.9, –2.4)**	–2.6 (–12.6, 1.4)
	losses R^2	0.24 (0.18, 0.32)	0.06 (0.03, 0.12)	0.10 (0.07, 0.17)	0.14 (0.07, 0.27)
	n	896	1259	3004	1875
Total (mixed effects)	$10^3 \times \beta$ losses	**4.6 (3.6, 6.4)**	**1.9 (1.3, 3.7)**	**3.8 (2.6, 7.7)**	**1.7 (0.6, 2.9)**
	$10^7 \times \beta$ losses^2	**–7.3 (–18.1, –4.3)**	**–3.3 (–13.9, –2.1)**	**–4.6 (–34.7, –2.6)**	–2.8 (–10.9, 1.2)
	losses variance explained	0.15 (0.06, 0.29)			
	n	7034			
EGMs	$10^3 \times \beta$ losses	**6.4 (5.2, 10.5)**	**3.3 (1.3, 8.3)**	**38.3 (23.2, 51.6)**	**5.5 (2.9, 20.8)**
	$10^7 \times \beta$ losses^2	**–13.2 (–45.3, –9.2)**	**–8.3 (–38.7, –2.0)**	–627.6 (–1207.5, 118.0)	**–9.9 (–322.2, –2.1)**
	losses R^2	0.26 (0.19, 0.36)	0.04 (0.01, 0.18)	0.20 (0.05, 0.32)	0.23 (0.15, 0.52)
	n	619	462	1156	180
Lotteries	$10^3 \times \beta$ losses	1.1 (–5.5, 6.1)	**12.2 (4.3, 20.4)**	**6.2 (4.2, 11.0)**	3.1 (–1.9, 5.6)
	$10^7 \times \beta$ losses^2	35.8 (–67.1, 193.7)	**–450.2 (–846.5, 12.6)**	**–43.4 (–231.4, –28.6)**	–30.8 (–59.5, 314.3)
	losses R^2	0.02 (0.00, 0.06)	0.02 (0.01, 0.05)	0.04 (0.01, 0.10)	0.03 (0.00, 0.10)
	n	722	1073	2700	1943
Racing	$10^3 \times \beta$ losses	**2.7 (0.7, 5.5)**	7.9 (–7.7, 43.8)	–1.1 (–3.9, 5.8)	0.8 (–0.9, 8.2)
	$10^7 \times \beta$ losses^2	–1.7 (–17.5, 16.2)	–200.9 (–1686.9, 287.0)	6.6 (–53.0, 16.0)	–3.4 (–63.8, 5.6)
	losses R^2	0.05 (0.00, 0.16)	0.00 (0.00, 0.76)	0.10 (0.00, 0.36)	0.11 (0.03, 0.60)
	n	453	68	215	101
Sports betting	$10^3 \times \beta$ losses	–0.9 (–28.0, 14.3)	8.0 (–7.1, 17.3)	**9.7 (3.7, 15.5)**	**4.5 (2.1, 10.2)**
	$10^7 \times \beta$ losses^2	–51.5 (–417.0, 1618.9)	–58.3 (–156.7, 450.1)	–49.2 (–225.4, 32.3)	**–28.3 (–134.5, –11.5)**
	losses R^2	0.00 (0.00, 0.24)	0.08 (0.05, 0.26)	0.06 (0.00, 0.21)	0.15 (0.08, 0.29)
	n	175	222	435	402
Table games	$10^3 \times \beta$ losses	4.1 (–3.4, 10.2)	1.0 (–5.9, 3.8)	30.1 (–11.6, 51.0)	0.0 (–0.9, 2.2) [a]
	$10^7 \times \beta$ losses^2	–28.3 (–114.6, 66.5)	–4.9 (–25.8, 80.3)	–225.9 (–1023.7, 3783.1)	0.3 (–10.8, 3.8) [a]
	losses R^2	0.00 (0.00, 0.16)	0.00 (0.00, 0.24)	0.12 (0.00, 0.45)	0.21 (0.00, 0.90) [a]
	n	169	126	172	31

Player loss β coefficients estimated from multiple linear regression or mixed effects linear models. Parentheses report 95% confidence intervals, estimated via the percentile method from an ordinary, non-parametric bootstrap with 5000 replications. Estimates where the 95% confidence interval does not contain zero are indicated by bold type. Estimated coefficients are not reported for socio-demographic predictor variables for reasons of brevity. Non-reported predictor variables include: age; age^2; sex; education level; marital status; employment status; household income; and household income^2. Losses R^2 reports the variance explained by the player loss terms in the regression, after adjusting for other covariates. Losses R^2 was calculated by subtracting the adjusted R^2 of the full multiple linear regression from that of a multiple linear regression specified identically except with the player loss terms dropped. [a]Indicates that due to the small number of observations, the linear regression was specified without socio-demographic predictor variables. EGMs = electronic gambling machines.

variation in problem gambling risk, depending on country and gambling activity, with gambling on EGMs in Australia and Norway showing the strongest evidence for r-shaped curves. However, losses on lotteries and table games in particular explained very little variation in problem gambling scores. The sensitivity analysis for missing data found few substantive changes (online Supporting information, Tables S4–S26). The sensitivity analyses suggested that total gambling losses in Australia and lottery losses in Canada may be linear rather than r-shaped, while racing in Canada may have an r-shaped dose–response curve.

DISCUSSION AND CONCLUSIONS

Key results

The risk curves for total gambling losses showed no evidence of J-shaped relationships between loss and risk. Where previous studies [6,7] found J-shaped curves, in this study r-shaped and linear curves describe the loss–risk relationship more accurately. Linear regression analysis confirmed these findings, with significant r-shaped curves found for total gambling losses in Australia, Canada and Finland and a linear curve found in Norway. The mixed-effects linear model estimates were comparable with the unpooled estimated from multiple linear regression. Furthermore, none of the 20 activity-specific risk curves appeared to be J-shaped. Risk curves either appear to be r-shaped or linear. However, some linear risk curves had flat gradients (e.g. table games in Australia), implying that for these activities risk is not related directly to the magnitude of player losses. Indeed, considerable variation was evident among risk curves. EGM gambling was the activity at which losses correlated most strongly with harms. Little relationship was found between losses and harm for table games, with relationships varying between countries for lotteries, racing and sports betting.

Limitations and generalizability

These findings are subject to four important limitations. First, due to the format of household income data in survey questionnaires, this study used absolute amounts lost by gamblers as the explanatory variable, rather than proportions of household income. Use of proportions of income may improve face validity. Second, these estimates rely upon self-reported player losses. These are likely to underestimate true losses for activities such as EGMs [1,21]. Third, the differences between survey instruments used in these surveys means that risk curves are not strictly comparable between countries. In particular, the use of different questions to estimate gambling losses is likely to impact upon the gradients of harm–loss curves. Differences in curve shape between countries may be due in part to different inclusion criteria employed in the surveys (e.g. whether weekly or life-time gamblers were administered the problem gambling screen). Fourthly, these risk curves are based on cross-sectional studies. As recent longitudinal studies (e.g. [17–19]) found that EGM gambling is a strong predictor of the future onset of gambling problems, we conjecture that similar relations may be found prospectively.

The generalizability of specific risk curves across gambling contexts is limited, as the socio-technical determinants of gambling risk vary between jurisdictions and over time. For example, the replacement of EGMs with more restricted machines in 2009 in Norway means that the risk curves documented here for EGMs may no longer apply. Caution should therefore be exercised when generalizing to other jurisdictions or within the same jurisdiction if the accessibility of gambling products or their characteristics has altered. Nevertheless, if the gambling environment remains constant, we see little reason to expect the shape of these risk functions to vary over time. While the rate of problem gambling has plateaued in some jurisdictions, consistent with the 'adaptation hypothesis' [38], so too have per-capita gambling losses (e.g. [39]).

It may be suggested that r-shaped risk curves are incompatible with the well-known finding that problem gamblers account for a very large proportion of gambling losses. However, simulation results presented in Appendix 2 in the online supporting information shows that an r-shaped curve is consistent with a disproportionate problem-gambler loss share.

Implications and conclusions

There is little evidence supporting the hypothesis of J-shaped risk curves for total gambling losses. Previous studies showing J-shaped curves are methodologically flawed. Risk curves for total gambling losses are likely to be linear or r-shaped. This does not mean that there are no individuals who gamble large amounts of money without experiencing harms. Rather, every increase in consumption increases the risk of harm. In consequence, previous recommendations (e.g. [6,7]) regarding 'safe' levels of gambling should be disregarded and future guidelines must be made on the basis of tolerable levels of risk.

Where r-shaped curves are found, risks escalate most quickly per dollar for the initial dollars lost. After a certain sum of money is lost, increased losses appear to have a reduced impact upon the marginal risk of harm. It is probable that curve shapes depend on the type of harm examined and the instrument by which it is measured.

As previous studies demonstrate (e.g. [16]), different gambling activities appear to be associated with different risk functions. Some gambling activities have only a negligible association with harm, while EGMs exhibit a strong loss–harm relationship, stronger than that for total gambling losses. These relations appear to be moderated by national context. As such, one-size-fits-all consumption guidelines across gambling activities are likely to be inappropriate.

These findings have implications for the 'responsible gambling' model of regulation. Contrary to Shaffer's assertion that gambling entails a hormesis relationship [13], many gambling products appear to be more similar to tobacco than to alcohol, in that there is no threshold below which consumption does not increase risk. For EGMs in particular, every increase in consumption increases the risk of harm.

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Supporting information

Additional supporting information may be found in the online version of this article at the publisher's web-site:

Figure S1 Bootstrapped risk curves for total gambling losses versus problem gambling risk.
Figure S2 Bootstrapped risk curves for gambling losses versus problem gambling risk.
Figure S3 Risk curves for total gambling losses versus problem gambling risk.
Figure S4 Risk curves for gambling losses versus problem gambling risk for five gambling activities.
Figure S5 The gambling-related harm – gambling expenditure curve in a simulated population of gamblers where those with PGSI = 8 account for 42% of gambling losses.
Table S1 Multiple linear regression estimates of player loss – problem gambling risk curves by gambling activity, estimated using population weights.
Table S2 Characteristics of the simulated population of gamblers.
Table S3 Bivariate quadratic linear regression estimates of player loss – problem gambling risk curves in simulation.
Table S4 Missing data sensitivity analysis for Australia, total losses.
Table S5 Missing data sensitivity analysis for Australia, EGM losses.
Table S6 Missing data sensitivity analysis for Australia, lottery losses.
Table S7 Missing data sensitivity analysis for Australia, racing losses.
Table S8 Missing data sensitivity analysis for Australia, sports betting losses.
Table S9 Missing data sensitivity analysis for Australia, table game losses.
Table S10 Missing data sensitivity analysis for Finland, total gambling losses.
Table S11 Missing data sensitivity analysis for Finland, EGM losses.
Table S12 Missing data sensitivity analysis for Finland, lotteries losses.

Table S13 Missing data sensitivity analysis for Finland, racing losses.
Table S14 Missing data sensitivity analysis for Finland, sports betting losses.
Table S15 Missing data sensitivity analysis for Finland, table games losses.
Table S16 Missing data sensitivity analysis for Canada, total gambling losses.
Table S17 Missing data sensitivity analysis for Canada, EGM losses.
Table S18 Missing data sensitivity analysis for Canada, lottery losses.
Table S19 Missing data sensitivity analysis for Canada, racing losses.
Table S20 Missing data sensitivity analysis for Canada, sports betting losses.
Table S21 Missing data sensitivity analysis for Canada, table games losses.
Table S22 Missing data sensitivity analysis for Norway, total gambling losses.
Table S23 Missing data sensitivity analysis for Norway, EGM losses.
Table S24 Missing data sensitivity analysis for Norway, lotteries losses.
Table S25 Missing data sensitivity analysis for Norway, racing losses.
Table S26 Missing data sensitivity analysis for Norway, sports betting losses.
Box S1 R code used to produce the simulation.