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ABSTRACT

Objectives: To examine the associations among cigarette design features and tar yields of leading cigarette brands sold in the United States, Canada, Australia and the United Kingdom.

Methods: Government reports and numbers listed on packs were used to obtain data on International Organization for Standardization (ISO)/Federal Trade Commission (FTC) yields for the tar of 172 cigarette varieties sold in the United States, Canada, Australia and the United Kingdom. We used standardised methods to measure the following 11 cigarette design parameters: filter ventilation, cigarette pressure drop, filter pressure drop, tobacco rod length, filter length, cigarette diameter, tipping paper length, tobacco weight, filter weight, rod density and filter density.

Results: Filter ventilation was found to be the predominant design feature accounting for the variations between brands in ISO/FTC tar yields in each of the four countries. After accounting for filter ventilation, design parameters such as overwrap length, tobacco weight and rod density played comparatively minor roles in determining tar yields.

Conclusions: Variation in ISO/FTC tar yields are predicted by a limited set of cigarette design features, especially filter ventilation, suggesting that governments should consider mandatory disclosure of cigarette design parameters as part of comprehensive tobacco product regulations.

Following the first reports linking smoking to diseases in the 1950s, there was a movement to reduce the levels of tar, nicotine and (later) carbon monoxide (CO) emitted by cigarettes. In the 1950s, filter tips were introduced to allay consumers' concerns about the health risks of smoking, and to project an image of reduced harm.[1] Filters generally reduced constituent yields, but could have contributed to sustained smoking in the public. Following the Surgeon General's Report in the United States in 1964, ventilated filters, which could reduce tar emissions even further, began to emerge.[2] Filter ventilation, which uses rings of tiny holes in the tipping paper around the cigarette filter, allows air to enter the filter during puffing, thereby reducing machine-measured per-puff concentration of tar, nicotine and CO (TNCO).[3] Since the 1960s, significant decreases in the average machine-measured TNCO emissions have been achieved in the United States, the United Kingdom and other countries where standard testing is performed.[4–6]

Regulators in jurisdictions such as the European Union (EU), China and Malaysia have implemented maximal limits of TNCO emissions. For example, the EU introduced initial tar limits of 15 mg, which were decreased to 12 mg in 1998 and to 10 mg in 2004.[7] To meet these limits, manufacturers have had to alter the design of cigarettes. Recent evidence suggests that the major change in cigarettes to comply with the EU limits has been increased filter ventilation. In 1999, 10 brands from the United Kingdom tested averaged 12 mg tar (according to the International Organization for Standardization (ISO) method) and 4.2% ventilation. After the limits were set at 10 mg of tar, the same brands of cigarettes measured in 2005 yielded 10 mg tar using the ISO method and 24.3% ventilation.[8] No other physical parameters showed such dramatic changes.

Reductions in machine-measured TNCO have not translated into reduced disease risk for smokers.[5 9] This is because smokers tend to compensate for the machine-measured reductions in nicotine by increasing their smoke intake per cigarette and/or smoking more cigarettes.[10–18] In other words, humans do not smoke like the machine and machine yields are not predictive of human exposures.[4 5 19–21] Ventilation may promote larger puff volumes and the filter vents can be blocked by fingers or lips during smoking—both of these would increase smoke intake, making vents the primary design feature that facilitates smoker compensation.[3]

The role of cigarette design parameters other than ventilation on standard TNCO yields has not been extensively investigated outside the tobacco industry.[22 23] Even in countries like Canada, which have enacted comprehensive testing and product disclosure regulations, there is little information available on how cigarette brands differ on design parameters or how different design parameters might effect the smoke yields. The WHO Framework Convention on Tobacco Control (FCTC), the world's first international public health treaty, includes provisions for testing and regulating cigarettes.[24] To develop recommendations regarding which, if any, design characteristics should be considered for mandatory testing disclosure or regulation, it is critical to expand our understanding of design features and the extent to which they vary in different markets. Indeed, without a basic knowledge of how products are designed, differences or changes in toxicant emissions are difficult to interpret. This paper investigates how different cigarette design parameters of popular cigarette brands and brand varieties (that is, full-flavour, light and ultralight) sold in four countries (the United States, Canada, Australia and the United Kingdom) are interrelated and how these design parameters predict variation in ISO/FTC tar yields between different cigarette brands.

METHODS

Sample: cigarette brands

At least two varieties of each of the major brand families sold in the United States, the United Kingdom, Canada and Australia were used for analysis. Brand families were selected in each country that: (1) represented the major manufacturers, (2) featured multiple tar levels and/or descriptors (for example, "full-flavour," "light" and "ultralight" in the United States); and (3) were readily available in the retail environment. All varieties were filtered, king-size length (~ 80–85 mm) and non-menthol, unless otherwise noted. In total, 49 varieties from the United States, 38 from Canada, 54 from Australia and 31 from the United Kingdom were assessed, listed in appendix A. US cigarettes were purchased in Buffalo, New York, USA, in August 2005, Canadian cigarettes in Kitchener/Waterloo, Ontario, Canada, Australian cigarettes in Melbourne, Victoria, Australia (both in October 2005) and UK cigarettes in London, United Kingdom in November 2005. Across countries, tar yields in many brand families spanned from as low as 1 mg to as high as 19 mg. In the United States, no selected brand family featured an ultralow variety; the convention in the United States seems to be to market cigarettes yielding $\leqslant 3$ mg of tar as a separate brand family, rather than as a line extension.

Measures

The ISO TNCO yields were recorded from cigarette packs in Canada, Australia and the United Kingdom. Note that in Australia, tar yields are reported on packs only in categories of 16 mg, 12 mg, 8 mg, 6 mg, 4 mg, 2 mg and 1 mg. US Federal Trade Commission (FTC) yields for US brands in 2005 were obtained via Freedom of Information Act request, supplemented when necessary from the manufacturers' websites. (The FTC ceased issuing public reports of cigarette yields in 2000, but US law requires manufacturers to report the data to FTC.)

The FTC and ISO methods differ primarily in cigarette conditioning (24 hours vs 48 hours at 60% relative humidity and 22°C) and butt length, but use the same puffing parameters. Tar yields ranged from 4–19 mg in the United States (median 11 mg), 1–15 mg in Canada (median 9.5 mg), 1–10 mg in the United Kingdom (median 7 mg) and 1–16 mg (median 8 mg) in Australia.

Table 1 gives the definitions and descriptions of several cigarette characteristics that were assessed.[25 26] The pressure drop and filter ventilation measurements were recorded on 20 cigarettes from each pack using the KC-3 digital dilution and pressure drop apparatus (Borgwaldt-KC, Richmond, Virginia, USA). Filter pressure drop was assessed using the same apparatus by separating five filters from their tobacco rods (with the tipping paper still attached and the filters fully enclosed in the test barrel so that no vent holes were exposed during testing). Tobacco rod length, filter length, tipping paper length and their diameters were measured on five cigarettes using a digital caliper and recorded in millimetres (VWR, Philadelphia, Pennsylvania, USA). Overwrap length was calculated as the difference between filter length and tipping paper length. The tobacco from each of the five cigarettes was then emptied into a weighing dish and, using a digital balance (Mettler-Toledo AB-104s, Ohio, USA), the total weight in grams was recorded. The filters from each of the same five cigarettes were placed in a separate weighing dish and the total weight in grams was recorded. These total weights were then divided by five to obtain average per-cigarette weights. Tobacco rod density was calculated from the weight of tobacco (converted to milligrams), divided by the volume of the tobacco rod (volume $= \pi \times \frac{1}{2}(\text{diameter})^2 \times$ rod length), with lengths converted to centimetres—hence, density is expressed as milligrams per cubic centimetre (mg/cm^3). A similar calculation was used to determine filter density.

The testing room had an average temperature of 22.7°C (range 21.2–25.4°C) and average relative humidity of 36% (range 16–67%) during the testing period. Humidity at the time of testing was modestly correlated with tobacco weight ($r = 0.22$, $p<0.01$), but not other parameters.

Data analysis

Data were assessed in SPSS V.14.0 using correlations, analysis of variance, multiple linear regression and ordinal logistic regression (cumulative logit model). All design parameters were treated as continuous variables. Tar yields were treated as continuous in the United States, the United Kingdom and Canada, and as ordinal in Australia.

Table 1 Descriptions of design features and physical parameters assessed in this study

Measure	Units	Explanation*
Filter ventilation	%	Percentage of smoke that is diluted by air when a smoker takes a puff. Filter ventilation is measured at 17.5 ml/s flow rate
Cigarette pressure drop	mm water	Also known as draw resistance. Expression of the effort/pressure required to move air through a whole cigarette at a flow rate of 17.5 ml/s. Contributes to smokers' acceptance of the product, as smokers find excess or insufficient draw resistance unacceptable
Filter pressure drop	mm water	Filter pressure drop represents the effort required to draw air through the filter. Indirectly related to smoke removal efficiency
Tobacco rod length	mm	Length of tobacco filler
Filter length	mm	Length of filter
Cigarette diameter	mm	Width of the rod. Smaller diameter leads to less tobacco being burned and to increased oxygen availability during combustion, leading to lowered levels of tar, nicotine and other particulates
Tipping paper length	mm	Distance from the end of filter to end of tipping paper. Tipping paper attaches the filter tip to the tobacco rod. The difference between this and filter length determines "overwrap" length
Tobacco weight	g	Amount of tobacco matter in the cigarette. Levels of smoke constituents are directly related to the amount of tobacco that is burned
Filter weight	g	Mass of the filter. Related to smoke removal insofar as it indirectly measures the number of cellulose acetate fibres on which smoke particles can impact
Rod density	mg/cm^3	Calculated from observed tobacco weight, rod length and diameter. Gives an estimate of average cigarette packing density
Filter density	mg/cm^3	Calculated from observed filter weight, length and diameter. Associated with particle removal efficiency (filter efficiency). A denser filter should trap more particles, assuming no differences in the fibre denier or number of fibre cross-connections from the plasticiser

*Sources: Browne[25] and Norman.[26]

Table 2 Correlations among standard machine yields and physical parameters across countries

	Ventilation	Cigarette PD	Cigarette diameter	Rod length	Filter length	Tipping length	Tobacco weight	Filter weight	Rod density	Filter density	Filter PD
Tar	−0.93*	0.60*	−0.01	−0.63*	0.39*	0.51*	−0.46*	−0.42*	0.42*	−0.06	−0.71*
Nicotine	−0.87*	0.61*	0.12	−0.67*	0.47*	0.58*	−0.48*	−0.44*	0.41*	−0.11	−0.67*
CO	−0.94*	0.65*	−0.01	−0.59*	0.35*	0.45*	−0.41*	−0.42*	0.37*	−0.1	−0.66*
Ventilation (%)	1	−0.69*	0	−0.33*	0.40*	0.56*	−0.40*	0.41*	−0.32*	0.11	0.69*
Cigarette PD (mm H_2O)		1	−0.07	0.23*	−0.30*	−0.37*	0.44*	−0.14	0.44*	0.20*	−0.12
Cigarette diameter (mm)			1	0.24*	−0.15	−0.15**	0.21*	−0.17**	−0.35*	−0.56*	−0.17**
Tobacco rod length (mm)				1	−0.87*	−0.82*	0.65*	−0.75*	0.15	−0.14	−0.60*
Filter length (mm)					1	0.83*	−0.64*	0.77*	−0.25*	−0.03	0.57*
Tipping length (mm)						1	−0.60*	0.72*	−0.22*	0.14	0.63*
Tobacco rod weight (g)							1	−0.43*	0.76*	0.07	−0.44*
Filter weight (g)								1	−0.06*	0.44*	0.67*
Rod density (mg/cm^3)									1	0.42*	−0.16**
Filter density (mg/cm^3)										1	0.36*

PD, pressure drop.
*$p<0.01$, **$p<0.05$.

RESULTS

Table 2 shows the bivariate correlations among the selected cigarette design parameters and standardised TNCO yields pooled across all four countries. Of the 11 design parameters, filter ventilation is the parameter most clearly associated with FTC/ISO TNCO yields. However, nearly all the physical characteristics measured, except diameter and filter density, were significantly correlated with TNCO yields. Figure 1 shows the mean and SE for four design parameters for the tested cigarette brands from the US, Canada, Australia and the United Kingdom. Because the ranges of tar yields varied widely across the countries, design parameter means are also reported adjusted for tar. Tar was treated both as a continuous outcome (the United States, the United Kingdom and Canada only) and a categorical outcome in Australia. Ventilation, tipping paper length, tobacco weight and filter weight showed the most dramatic differences across countries. In terms of ventilation, Australian cigarettes tested were an average more ventilated than brands from the other three countries. When adjusted for tar, US brands showed greater overall ventilation. For the other parameters, the cross-country differences are not significantly altered when controlling for tar yields.

Multivariate models to predict ISO/FTC tar yields

Given the dominance of ventilation in determining tar yields, ventilation level was entered first in each regression model, and other design features were tested subsequently to determine which, if any, added additional predictive power. Any design

Figure 1 Mean values for selected design parameters by country, unadjusted and adjusted for tar levels.

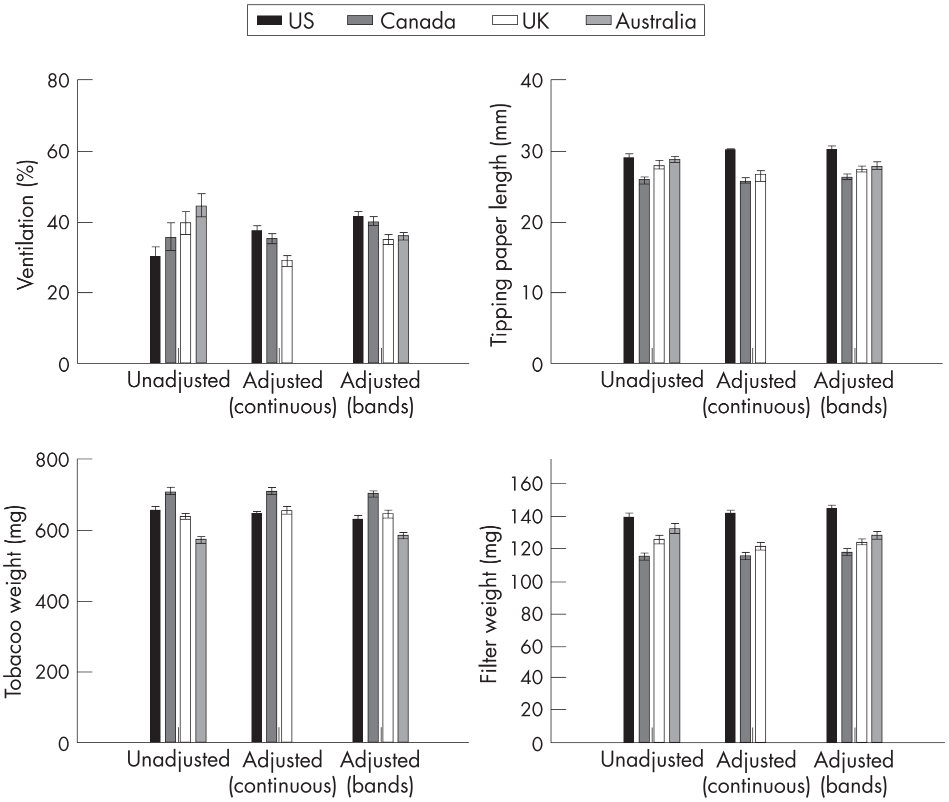

Table 3 Linear regression model predicting tar yield for brands purchased in the United States, the United Kingdom and Canada

	Δ-R^2	F	p Value	B	95% CI B	p Value
Intercept	–	–	–	4.05	0.07 to 8.04	0.05
Ventilation (%)	0.82	512.8	<0.001	−0.16	−0.18 to −0.15	<0.001
Tobacco weight (mg)	0.04	30.6	<0.001	0.008	0.003 to 0.013	0.003
Rod density (mg/cm^3)	0.01	12.5	0.001	0.03	0.01 to 0.05	0.002
Overwrap (mm)	0.004	3.3	0.071	−0.16	−0.33 to 0.01	0.071

parameter showing a p value of $\leqslant 0.10$ was considered in the model—given the relatively small sample size and the dominance of filter ventilation, it was thought a slightly higher threshold for significance was justifiable.

A combined model using US, Canadian and UK brands (table 3) showed that ventilation was dominant, accounting for a minimum of 86% of variance in tar yields). Three other factors emerged as additional predictors of yield: tobacco weight, rod density and overwrap (that is, tipping paper length − filter length). Overwrap could be considered as an indicator of unburnable tobacco under standard test conditions. Examining these models by country showed that some of these individual features were not significantly related to tar in some countries—for example, rod density in the United States ($p = 0.71$) and tobacco weight and overwrap in Canada ($p>0.40$).

To assess the relation between design and tar for Australian cigarettes, we used ordinal logistic regression (cumulative logit model). Here, ventilation alone accounted for ~ 95% of variance in tar category membership (by Nagelkerke's pseudo-R^2). Adding tobacco weight increased this to 96.7% ($p<0.001$ by nested χ^2); subsequent independent variables could not be added, because of near-complete separation of the data. The final coefficients were −0.48 (95% CI −0.69 to −0.28) for ventilation and 0.03 (95% CI 0.01 to 0.06) for tobacco weight. (Note that these cannot be directly compared to linear regression coefficients.) To check the consistency, we categorised the yields of US, UK and Canadian brands following the Australian brands and reproduced the model. The same model produced a pseudo-R^2 of 0.89, and coefficients of −0.29 (95% CI −0.35 to −0.22) for ventilation and 0.01 (95% CI 0.006 to 0.02) for tobacco weight across the three countries. Because the CIs for the coefficients overlap, we can conclude that the models are not significantly different. (Note that rod density and overwrap can be added to the US/UK/Canada ordinal model, with similar results to the linear model discussed above—data not shown.) Linear and ordinal models featuring nicotine and CO as the dependent variables yielded similar patterns of results (data not shown).

DISCUSSION

Filter ventilation was by far the most important cigarette design feature accounting for variation in ISO/FTC tar yields of popular cigarette brands in each of the four countries, accounting for at least 85% and as much as 95% of variance. Factors such as tobacco weight, rod density and overwrap length played comparatively minor roles in determining the standard TNCO yields after accounting for filter ventilation. These findings are consistent with previous literature, indicating the centrality of filter ventilation among design features.[22 23] Overwrap length has also been shown to be an influence on standard tar yields.[27]

This study is subject to some limitations. A key limitation is the banding of TNCO yields in Australia, whereas they are reported continuously in the other countries. (As of 2006, Australia has removed information on tar bands from packs because it is misleading to consumers. Although we agree in principle, this also means that there is currently no source for ISO yield data on Australian cigarettes—the Australian government should consider making such data available to qualified researchers.)

This hampered comparability across sites and necessitated separate consideration for each country. However, the general consistency of results across countries suggests that ventilation is a key player regardless of the country. We did not measure tobacco blend, nicotine content and paper porosity, all of which could theoretically effect the standard TNCO yields.[28] We recognise that tar is limited in its value as a surrogate of toxicants in cigarette smoke, given the dependence of the constituent mix of smoke on tobacco blending—US cigarettes have a higher concentration of burley tobacco than Canadian, UK and Australian cigarettes, which are mostly bright tobacco. Cigarettes were not conditioned before testing for design parameters, which could introduce error into some of the measurements obtained. However, the room conditions were relatively stable, and this offers a simulation of cigarette conditions encountered by consumers, who typically would not bring their cigarettes to the 60% relative humidity and 22°C conditions of ISO testing before smoking.[23] The brands we tested were selected from major brand families, and not based on market share. We did not examine unfiltered brands, which probably have a different combination of design features influencing the tar yields. Finally, in the current study, we could not model how these design features and physical parameters relate to specific smoke constituents of potential interest to regulators, such as nitrosamines, polycyclic aromatic hydrocarbons, volatile organic compounds or free nicotine.

Despite these study limitations, this research represents a comprehensive examination outside the tobacco industry of how different cigarette design parameters relate to standard tar yields. We believe that the findings of this research have important implications for Article 9 and 10 of the World Health Organization's FCTC, which includes provisions for product testing and disclosure applicable to over 140 countries.[24] As parties to the treaty meet to decide on the regulation of tobacco products, they might strongly consider requiring manufacturers to disclose basic information about cigarette design. Arguments about trade secrets ought to be ignored, as reverse engineering is routinely performed by the manufacturers on competitors' products, often within days of introduction.[29] The WHO Study Group on Tobacco Product Regulation (TobReg) has already recommended the following list of design parameters and is preparing guidelines for the FCTC Conference of the Parties: aerosol particle size, filter ventilation, filter length, filter fibre residues, filter charcoal content, cigarette circumference, paper porosity, percentage of reconstituted tobacco, percentage of expanded tobacco, moisture content and product firmness.[30] The present data suggest that tipping paper length, tobacco weight and tobacco density would also be useful to request. As also illustrated in the present study, measuring a set of physical parameters can predict standard tar yields on the current ISO regimen to a high degree of accuracy (>90%). For countries with limited

What this paper adds

- Filter ventilation has been shown previously as a driving force behind the reduction in ISO machine-measured tar yields. However, its role in the context of other cigarette design features has not consistently been examined.
- Across 172 cigarette varieties from four countries, we demonstrate that filter ventilation is clearly the greatest determinant of ISO tar yields and that design features such as weight of tobacco, tobacco density and filter overwrap play comparatively minor roles. Governments should consider mandatory disclosure of cigarette design parameters as part of the comprehensive tobacco product regulations.

budgets for implementing expensive product-chemistry-testing regimes, simply measuring physical parameters offers an attractive cost-effective alternative method to monitor changes in brands over time or to check industry-reported data. (Note that this should not be construed as support for the 'benchmarking' concept advanced by the tobacco industry as a way to avoid testing brands under alternative smoking conditions as required by law in Massachusetts, United States and Canada.)

The importance of having government regulators monitor relevant cigarette design parameters can be seen in our results on filter ventilation. Cigarette manufacturers have used filter ventilation as an inexpensive way to reduce machine-measured TNCO yields. This can clearly be seen with the design features changed in the United Kingdom to meet the "10/1/10" standard, where the filter ventilation levels on full-flavour brands increased over four times.[8] Findings from this study also reveal that filter ventilation is correlated with lower cigarette pressure drop. This lends further support to the notion that ventilation facilitates compensation by enabling the smoker to take larger, higher velocity puffs.[3 31 32]

These data have demonstrated how cigarette manufacturers have carefully engineered their cigarette brands to give the illusion of lower smoke emissions and exposure to consumers. As discussions continue on revising the ISO regime and implementing tobacco product regulation, it is crucial to consider the effects of cigarette design parameters on both existing and proposed regimens. A cigarette is a complex system, and designing a testing system to account for only one design-related "cheat" of the system (for example, blocking vents) leaves the door open for other design tweaks to produce artificially low yields under the new system. Normalisation of constituent yields to nicotine yields is attractive, but should be explored in greater depth to identify potential ways it could be exploited by creative cigarette design. Parties to the Framework Convention on Tobacco Control should seriously consider requiring cigarette manufacturers to report information on the cigarette design parameters as an essential component of product regulation. Also, given the well established role of filter ventilation in smoker compensation, government regulators might consider banning filter vents and barring the use of machine-measured smoke emission data in all product marketing as it is clear that such data mislead consumers.

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