Secret science: tobacco industry research on smoking behaviour and cigarette toxicity

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A lack of scientific data remains the principal obstacle to regulating cigarette toxicity. In particular, there is an immediate need to improve our understanding of the interaction between smoking behaviour and product design, and its influence on cigarette deliveries. This article reviews internal tobacco industry documents on smoking behaviour research undertaken by Imperial Tobacco Limited (ITL) and British-American Tobacco (BAT). BAT documents indicate that smokers vary their puffing behaviour to regulate nicotine levels and compensate for low-yield cigarettes by smoking them more intensely. BAT research also shows that the tar and nicotine delivered to smokers is substantially greater than the machine-smoked yields reported to consumers and regulators. Internal documents describe a strategy to maximise this discrepancy through product design. In particular, BAT developed elastic cigarettes that produced low yields under standard testing protocols, whereas in consumers' hands they elicited more intensive smoking and provided higher concentrations of tar and nicotine to smokers. Documents also show that BAT pursued this product strategy despite the health risks to consumers and ethical concerns raised by senior scientists, and paired it with an equally successful marketing campaign that promoted these cigarettes as low-tar alternatives for health-concerned smokers. Overall, the documents seem to reveal a product strategy intended to exploit the limitations of the testing protocols and to intentionally conceal from consumers and regulators the potential toxicity of BAT products revealed by BAT's own research. Tobacco industry research underscores the serious limitations of the current cigarette testing protocols and the documents describe deceptive business practices that remain in place.

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Public pressure to reduce cigarette toxicity has grown in the 50 years since the discovery that smoking causes cancer and the release of the first US Surgeon General's report on smoking.[1] In response, the tobacco industry embarked on a series of design changes to reduce the tar yields of cigarettes when tested under the International Standards Organization (ISO) machine-smoking protocols (ie, 35 mL puffs drawn once per min for 2 s until a fixed butt length is reached).[2,3] Initially, these design changes seemed to have succeeded: the average sales-weighted tar yields of cigarettes tested under the ISO protocol decreased more than 44% between 1968 and 1997. This reduction in machine-smoked yields, however, has failed to translate into a similar reduction in health risk for smokers.[2,4,5] Rather, the main effect of these design changes has been to change how cigarettes are smoked. Smokers compensate for low-yield cigarettes by smoking them more intensely, to the extent that the machine-tested tar and nicotine levels currently bear little or no relation to the actual levels of tar and nicotine delivered to smokers.[6,7] In hindsight, the tobacco industry's low-yield strategy seems to have been more effective as a marketing campaign to keep health-concerned consumers smoking than as a public-health measure.[2]

In light of the industry's failure to reduce cigarette toxicity, the onus has shifted onto health authorities to develop an effective policy response. Despite the urgency of the task, authorities have yet to articulate an effective regulatory framework. For example, the EU is one of the few jurisdictions to have set limits on cigarette yields: effective from January, 2004, all cigarettes have had to yield a maximum of 10 mg of tar, 1 mg of nicotine, and 10 mg of carbon monoxide.[8] The initiative behind this policy is laudable; unfortunately, the policy is based on the same ISO machine-testing protocols and standard yields that have failed to correlate with human measures of exposure and health outcomes.

Any policy that seeks to limit smoke constituents will be meaningless unless it is based on valid testing protocols that are relevant to human smokers. WHO is currently holding discussions with scientists, regulatory agencies, and the ISO with the aim of revising the ISO testing protocols. However, there is a lack of evidence to guide these developments.[9] At present, even basic data on the normal parameters of puffing behaviour that could serve as valid benchmarks for new testing protocols are lacking. There is also an urgent need to assess how puffing behaviour responds to cigarette design and how this interaction affects cigarette deliveries.

In each of these areas, there is insufficient evidence to guide regulatory policy. Moreover, of the research that has been conducted, nearly all of it has been undertaken by the tobacco industry. Although much of this research remains confidential, glimpses into industry science are available through internal documents released through court disclosure. These documents represent a rich source of data for human smoking behaviour, and provide insight into the tobacco industry's internal product strategies and general conduct. This insight is critical for policymakers to anticipate the tobacco industry's response to new testing protocols and to frame regulatory policies accordingly.

The current study reviews research on the interaction between smoking behaviour and product design conducted by British American Tobacco (BAT) Limited

and its Canadian subsidiary, Imperial Tobacco Limited (ITL), with a particular focus on the implications for regulatory testing protocols.

Methods

The current review was done on tobacco industry documents released as a result of litigation initiated by Attorneys General of the United States. The set of documents, which first became available in 1998, has since been enlarged by the addition of documents related to subsequent lawsuits. Eight tobacco companies (BAT and its US subsidiary, Brown and Williamson; R J Reynolds; American Tobacco; Lorillard; The Tobacco Institute; the Council on Tobacco Research; and Philip Morris) made these documents available on various websites and in two depositories located in Minnesota, USA, and Guildford, England. Among the documents produced were the scientific research papers of BAT and its subsidiaries, including ITL. This review identified documents related to research by BAT and ITL during the 1970s to 1990s into human smoking behaviour and its relation to cigarette design. The documents were collected between 1999 and 2004 by various methods, beginning with a review of files at BAT's depository in Guildford. This initial search was supplemented by an electronic search for documents using author, key words (human smoking, ISO, human mimic, testing protocols, puffing behaviour, smoking topography, puff volume, cigarette yields, elasticity, and delivery), and report or file number. Many of the documents initially identified were included in a browsable website, which has since been discontinued and its contents have now been integrated into the comprehensive tobacco document site Tobacco Documents Online. They appear in searchable form in the Guildford subset of Tobacco Documents Online. Most of this early collection of BAT documents is also available in searchable form in the British American Tobacco Documents collection at the University of California, San Francisco. All electronic links have been updated to correspond with either the Tobacco Documents Online or University of California, San Francisco collections.

For **Tobacco Documents Online** see www.tobaccopapers.org

For the **Guildford subset of Tobacco Documents Online** see http://tobaccodocuments.org/guildford_subset/

For the **British American Tobacco Documents collection** see http://library.ucsf.edu/tobacco/batco/

Results

As early as 1967, BAT scientists recognised a fundamental need to understand how a smoker uses and manipulates cigarettes to obtain satisfaction.[10] Puffing behaviour, or smoking topography, provided the link between the product and the subjective experience of smoking. As the technology to measure human puffing behaviour improved, smoking topography became an increasingly important component of product testing and a valuable tool for understanding the relation between puffing behaviour and constituent delivery: "The perceptions of mechanics are the first product attributes to which a smoker is exposed…The behaviour and delivery of these puffs elicit a perception of irritation, which in turn influence the behaviour and the delivery of subsequent puffs."[11] Beyond the mechanical role of puffing in determining the taste and strength of a product, the sensory experience serves as an important form of feedback in its own right. Indeed, to satisfy consumers a brand must "supply the adequate levels of impact, irritation, and taste . . . with a mechanics that do not require the smoker to work too hard."[11] Ultimately, smoking topography became a useful tool for understanding smokers' needs and how different products could meet and even shape those needs.

Behavioural compensation

As BAT documents throughout the period make clear, a smokers' primary need is nicotine: "It is accepted that nicotine is both the driving force and the signal for compensation in human smoking behaviour."[12] Consumers smoke to achieve a certain level of nicotine and will alter their smoking behaviour to regulate this level throughout the day.[13,14] Given that the average smoker consumes only 30% of the available tobacco in each cigarette, there is substantial opportunity for smokers to regulate their intake by varying how they smoke each cigarette, including changes to the number, size, and velocity of puffs.[15] In fact, smokers typically alter their puffing behaviour even during the course of a single cigarette in response to the sensory cues of smoking and the immediate pharmacological effects of nicotine.[16]

Perhaps most important, smokers also adjust their smoking behaviour to compensate for different nicotine levels between products: "We can assume that smokers will alter their smoking patterns, as well as their attitudes when they smoke cigarettes offering a lower nicotine content than they normally want."[17] A subsequent study assessing the effects of switching to a lower-yield brand reported: "Changes in the number, duration and volume of puffs were noted, as well as butt length and pressure drop differences. In each case, the smoker adjusted his smoking habits in order to duplicate his normal cigarette intake."[18]

Compensation has important implications for understanding the relative risk of different tobacco products: brands that give the appearance of being less toxic under standard testing conditions could actually confer little or no benefit in consumers' hands. Despite strong evidence of compensation from independent research,[2] the tobacco industry has yet to fully acknowledge the extent to which smokers regulate nicotine levels across products.[19]

In fact, BAT's internal research on compensation from as early as the 1970s is more consistent with the findings of independent researchers than its own public stance on the issue.[17,20] A report from 1977, entitled *The Effects of Changing Brands on Smoking Behaviour*, showed that "the smokers in this panel compensated for changed deliveries using most and sometimes all of the methods available to them simultaneously".[21] An earlier study

from 1972 concluded: "If the drop in nicotine content is not too great, then successful compensation by the smoker should be relatively easy to achieve."[17] Colin Grieg, a senior BAT researcher, summarised the research on compensation as follows: "Many people will tell you authoritatively that, on sound statistical analysis of well designed experiments, low tar smokers do not compensate. Rubbish."[22]

Parameters of human smoking behaviour

Product design also has implications for understanding puffing behaviour at the population level of smokers. Widespread changes, such as the introduction of filter ventilation, seem to have shifted the normal parameters of puffing behaviour toward more intensive smoking: "We have found a trend within the department for smokers to increase the volume of smoke drawn from cigarettes as the standard deliveries have been reduced by manufacturers."[23] Although it is not apparent whether puffing behaviour among human smokers was ever similar to the standard ISO machine puffing regimes, the discrepancy between the two continues to grow. The size of this discrepancy and the actual parameters of human puffing behaviour are important not only to understand compensation, but also to determine the validity of the ISO puffing regime used to test products, as well as the validity of the constituent yields that are reported to regulators and consumers.

Human puffing behaviour will inevitably be more variable than any machine-based testing protocol. Yet the issue is not simply whether human smoking is more variable, but whether it is systematically different from the testing protocols. To examine this issue we identified BAT studies between 1972 and 1994 that reported both standard (ie, ISO) and human measures of puffing behaviour. For each of the six studies identified, every parameter observed among human smokers—puff volume, puff frequency, puff number, and flow rate—was greater than for the ISO puffing regime.[11,24–28] Indeed, BAT research suggests that human smokers typically draw puff volumes almost twice as large as the ISO smoking machine (about 50–70 mL *vs* 35 mL, respectively), and at twice the rate as the ISO smoking machine (every 30 s *vs* every 60 s). Overall, human smokers typically inhale twice the total volume of smoke as the ISO smoking machine.[18,26,29] One senior BAT researcher commented on the systematic differences between human puffing behaviour and the ISO protocol in 1977: "Of the 165 R&D [research and development] smokers screened with profile recording units, there are fewer than 20% who take puffs of an average volume less than 35 mL. Fifty percent take puffs that average 35–55 mL and the remaining smokers take even larger puff volumes on their regular brands."[21]

Even taking into account the natural variations in puffing behaviour across smokers and different brands, the evidence is clear: "Consumers tend to take higher puff volumes, in the same or slightly lower duration, with much shorter interpuff intervals than the standard smoking regime. On this basis, it would be reasonable to assume that a significant proportion of consumers would tend to generate more smoke than indicated by the standard machine delivery."[25]

Human versus nominal cigarette yields

The systematic differences between human puffing and the ISO regime were large enough that BAT researchers began to question the use of the ISO protocol for testing their own products. A BAT position paper on smoking behaviour published after 1990 noted: "If a smoker forms a sensoric evaluation on a product after taking 70 mL puffs every 30 seconds, then it may not be appropriate to compare this with the chemistry of smoke generated by machine through puffing 35 mL every 60 seconds."[16]

Indeed, even modest differences in puffing behaviour can have a significant effect on the tar and nicotine delivered to smokers. Variations in puff volume and puff frequency—the two components of the total smoke intake—have the greatest effect on cigarette yields.[11] Nicotine and tar deliveries also increase with each subsequent puff due to reduced filtration by the shortening tobacco rod and because there is less diluting air coming through the cigarette paper and more air coming through the coal.[30] Puffing behaviour can also affect the relative amounts of tar and nicotine in mainstream tobacco smoke: "Clearly, the absolute deliveries will be different . . . Perhaps more importantly, though, the ratio of components within the smoke may be different."[16] For example, the tar to nicotine ratio may decrease under greater puff volumes as the available nicotine is diluted by a greater production of tar.[16]

Although total smoke intake is the most important determinant of cigarette yields, the velocity of a puff, or flow rate, also has implications for nicotine and tar yields.[31] For example, greater flow rates increase delivery by reducing the proportion of diluted air entering via the filter and increasing the concentration of the smoke in each puff.[31,32] Greater flow rates can also increase the free versus the bound nicotine ratio.[33] Free nicotine increases the bioavailability of nicotine and may represent an important means of manipulating the addictiveness of a product.[34]

The table[18,29,32,35] compares yields from cigarettes smoked using the standard ISO puffing regime (eg, 35 mL puffs, drawn for 2 s, once per min), with human-mimicked yields, generated by having the same machine smoke cigarettes using actual puffing behaviour recorded from human smokers for the same brand. The ISO protocol systematically underestimates the yields obtained by human smokers. C McBride, an ITL scientist, summarised data from one of these studies by noting that, one can "reasonably conclude that virtually all smokers are receiving substantially higher deliveries". [11]

		Intake (mL)	Nicotine (mg)	Tar (mg)	CO (mg)
1. Players Regular[18]	ISO (Machine)	277	1·4	25·3	
	Human	448	2·3	41·0	..
	Difference	+62%	+64%	+62%	
2. Matinée Regular[18]	ISO (Machine)	245	0·5	11·0	
	Human	274	0·7	12·9	..
	Difference	+12%	+51%	+17%	
3. Matinée Special[32]	ISO (Machine)	298	0·7	9·1	16·2
	Human	474	0·9	11·4	11·2
	Difference	+59%	+22%	+25%	+6%
4. Matinée Special—Modified[32]	ISO (Machine)	312	0·9	10·1	9·2
(High pressure drop, low efficiency	Human	548	1·1	13·4	13·1
filter)	Difference	+76%	+30%	+33%	+42%
5. "Popular" Canadian Brand[29]	ISO (Machine)	284	1·4	15·4	16·0
	Human	507	1·5	18·0	18·3
	Difference	+79%	+5%	+17%	+14%
6. Players Extra Light[35]	ISO (Machine)	350	0·6	7·1	
	Human	445	1·1	15·2	..
	Difference	+27%	+86%	+114%	

*Human levels refer to the constituent yields generated when cigarettes were machine smoked using puffing behaviours recorded from individual human smokers.

Table: **Total smoke intake and constituent yields under human smoking* versus ISO testing regimes, by brand**

Brand elasticity as a product strategy

The discrepancy between the ISO yields and the nicotine and tar delivered to human smokers is not simply an historical accident, but exists by careful design. Indeed, industry scientists were not only aware of behavioural compensation, but developed strategies to facilitate and reward compensation.[36–38] As Colin Grieg explained in a presentation to his BAT colleagues, the idea was " . . . to produce a cigarette which can be machine smoked at a certain tar band, but which, in human hands, can exceed this tar banding."[22] This product strategy was articulated in more detail at an international conference of BAT researchers and marketers the following year in Rio de Janeiro: "The challenge would be to reduce the mainstream nicotine determined by standard smoking machine measurement while increasing the amount that would actually be absorbed by the smoker."[39] G Brookes, another senior researcher speaking at the same conference, noted: "We should strive to achieve this effect without appearing to have a cigarette that cheats the league table [of ISO tar yields]. Ideally it should appear to be no different from a normal cigarette . . . It should also be capable of delivering up to 100% more than its machine delivery."[40]

This strategy spawned a new design concept whereby cigarettes would provide greater reward to smokers for a given puff volume: "Whatever the outcome of the various public debates on compensation and test procedures, we must aim to use our knowledge to develop products that respond to human smoker needs. The concept of smoke elasticity can be expected to play an important role."[41] Elasticity refers to an occurrence whereby the concentration of tar and nicotine in cigarette smoke increases as puff volume increases.[42] In other words, elastic cigarettes not only enable more intensive puffing in human hands, but also produce greater concentrations of tar and nicotine for a fixed volume of smoke at puffing levels typical of human smokers, relative to the standard ISO machine puffing regime. This event is illustrated by brand 6 listed in the table: a 27% increase in smoke volume yielded a much larger increase in nicotine (+86%) and more than doubled the tar level (+114%).

BAT designed elastic brands primarily by manipulating the tobacco blend and the pressure drop of cigarettes.[42] A research report from 1979 outlines the options in terms of pressure drop: "There are three major design features which can be used either individually or in combination to manipulate delivery levels; filtration, paper permeability, and filter-tip ventilation."[43] A 1994 paper gives an example: "A cigarette constructed with low paper porosity but with filter tip ventilation would more readily allow a smoker to take a higher delivery of smoke by increasing the velocity of puffing."[27] Not only do smokers of ventilated products modify their smoking behaviour by increasing their puff volumes, but also the greater velocity at which they puff decreases the filter efficiency and increases the concentration of the smoke.[32] One fairly typical study found that increasing the filter tip ventilation of a brand by 34% resulted in 16% greater smoke intake, but a 22% increase in tar and a 35% increase in nicotine.[32]

The practice of designing ostensibly low-yield brands that actually delivered more tar and nicotine to smokers raised ethical concerns among some of BAT's senior scientists. For example, in 1984, David Creighton, a senior research scientist working in the commercial applications division at BAT, questioned the way elastic cigarettes were being marketed: "Is this an ethical thing to do? People who buy an 8 mg product expect to get 8 mg . . . If a declaration that this product is elastic is made (which is the honest thing to do) then it could

upset the apple cart."[44] Not wanting to upset the apple cart, BAT decided to keep its research on elastic cigarettes secret.[45] Whatever design changes were introduced to increase elasticity, it was agreed that they should be subtle: "The consensus is that small improvements in elasticity which are less obvious, visually or otherwise, is likely to be an acceptable route."[12] Furthermore, "large changes in delivery are not credible (ie, 1 mg machine delivery giving 10 mg through the consumer compensation). Better to have a 9 mg product giving 15 mg."[12]

Despite the ethical concerns of its scientists and the health risks to consumers, elastic cigarette design soon became an important part of BAT's overall product strategy. In a presentation entitled BAT stance on compensation, C I Ayres communicated this policy to an international audience of BAT researchers and executives: "From a research and product development viewpoint the proposition of designing a cigarette, of high taste to tar ratio, which responds positively to human smoking behaviour has been agreed to be acceptable."[12] In other words, BAT designed a class of cigarettes which could, on the basis of its own research, deliver significantly more toxicants to smokers than the ISO numbers printed on packages and advertisements, and kept this product strategy secret from consumers and regulators.

Discussion

Tobacco-industry research represents a rich source of information on human smoking behaviour. BAT documents clearly show that human smoking behaviour is not simply more variable than standard testing protocols, but systematically greater in virtually every case. The documents also provide extensive support that smokers regulate their cigarette consumption to achieve a certain nicotine level and intensify their puffing behaviour when smoking low-yield cigarettes. These findings are important given that the tobacco industry has yet to fully acknowledge the addictive nature of its products and the extent to which smokers compensate for nicotine.

According to the documents in the current review, not only has BAT been aware of compensation for several decades, but it built a product strategy upon it. In response to internal research identifying that the tar and nicotine delivered to smokers was substantially greater than the standard yields, BAT sought to maximise this discrepancy through product design. The health implications of this strategy were clear: as F J Roe, a medical consultant to BAT, noted in1978, "Perhaps the most important determinant of the risk to health or to a particular aspect of health is the extent to which smoke is inhaled by smokers. If so, then deeply inhaled smoke from low tar delivery cigarettes might be more harmful than uninhaled smoke from high tar cigarettes."[46] Indeed, independent evidence suggests that the changes in inhalation patterns induced by low-yield cigarettes could have contributed to a recent increase in the incidence of adenocarcinoma of the lung among smokers.[47,48]

Despite the risk to consumers, BAT pursued this product strategy and paired it with an equally successful marketing campaign that promoted these cigarettes as low-tar alternatives for health-concerned smokers.[49] BAT was aware of the duplicitous nature of this strategy and set a policy to suppress outside knowledge of their research on smoking behaviour.[45] In particular, they attempted to suppress any research that might hasten a change in the regulatory testing protocols: "The FTC [Federal Trade Commission], and other authorities, may call for a change in the standard smoking machine test procedure. Around the group, the strategy, therefore, should be to do everything possible to maintain the present standard test procedure. If, however, the FTC or any other authority takes action to change the procedure, the strategy should then be to stretch out the discussions (both with the authorities and later at ISO) until exhaustive studies have established that an alternative procedure was in fact more relevant."[39] Thus, at the same time as BAT was secretly exploiting the limitations of the standard protocols, they publicly argued its merits and sought to delay its revision.[50] The industry's strategy of impeding more valid testing standards represented a wilful attempt to withhold fundamental information about the toxicity of its products from consumers and regulators.

It should be noted that our understanding of BAT research on smoking behaviour is limited to the documents that the tobacco companies turned over through litigation, and does not include documents that were withheld, destroyed, or are otherwise unavailable. Additionally, many of the brand specifications quoted in this review might have changed since these documents were written. Nevertheless, these findings are consistent with other reviews on the tobacco industry undertaken during the same period, especially since they relate to modifying product design and manipulating cigarette deliveries.[51–53]

Overall, these documents depict a deliberate strategy whereby BAT and ITL designed products that would fool their consumers and regulators into thinking these products were safer or less hazardous when they were not. The documents show no attempt to tell the truth to their consumers about these compensatable, elastic cigarettes. For example, an ITL press release on elastic cigarettes from 1999 states that, "Imperial Tobacco has never been guided by this concept in the design of its new products, or in modifications to products currently on the market."[54] Failure to disclose this product strategy and its health implications represents a breach of public trust. Moreover, this product strategy remains in place today, as does the tool of its deception, the ISO cigarette testing protocols. The current review leaves little doubt

that the ISO standards should be discarded in favour of new standards that meet the needs of consumers and regulators, rather than the tobacco industry.[55]

Conflict of interest statement
We declare that we have no conflict of interest.

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