Smoking behaviour and compensation: A review of the literature with meta-analysis

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ARTICLE INFO

ABSTRACT

The extent of compensation when switching to lower yield cigarettes is important for assessing risk of reduced yield products. Both completeness of and reasons for compensation are judged differently in the scientific and health community. We quantified compensation in a meta-analysis of suitable cross-sectional and brand-switching studies. For each dataset, we derived a compensation index (CI), 1 indicating complete and 0 no compensation. Meta-analyses provided overall estimates. We also reviewed evidence on compensation for nicotine and other factors. The unweighted mean CI (95% confidence interval) was 0.628 (0.513 to 0.742) from 38 estimates from 26 cross-sectional studies, and 0.723 (0.651 to 0.796) from 23 estimates from 19 brand-switching studies. Inverse-variance weighted estimates were 0.781 (0.720 to 0.842) and 0.744 (0.682 to 0.806). Brand-switching data indicate smokers compensate more completely over a narrower yield range. Smokers predominantly compensate by changing puffing volume, and little by changing cigarette consumption. The findings support compensation for nicotine, but other factors may also be relevant. Further investigation is needed using larger studies and different approaches to elucidate their role. We conclude that smokers switching to lower-yield cigarettes only partially compensate. Pharmacological nicotine effects are important, but other factors, including cigarette draw resistance, sensory effects of nicotine and conditioned stimuli may also contribute.

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1. Introduction

In 1999, one of us (GS) published a review on compensatory smoking (Scherer, 1999). Compensation was by no means a recent issue then, dating back to the 1940s (Finnegan et al., 1945; Johnston, 1942), with most studies published in the 1970s and 1980s. Since 1999, many additional studies on smoking and compensation have been published, generally using improved study designs, test products (cigarettes) and analytical methodologies. These undoubtedly extended our knowledge on this issue, which is equally relevant to public health, consumers (smokers) and the tobacco industry. Important recent events ('milestones') in the field of smoking and tobacco control with direct or indirect impact on the compensation issue are summarized in Table 1. Note that the Institute of Medicine Report (IOM) Report, the Family Smoking Prevention and Tobacco Control Act of 2009, and the Draft Guidelines for testing of Modified Risk Tobacco Products (MRTPs) (listed in Table 1) are not directly related to compensational smoking. However, they are mentioned here, because the product evaluation strategies they outline would not accept new products to be classified as PREPs or MRTPs, if significant compensation occurs when using these products. We consider it important to determine how the consumer is using a new tobacco product (for example by measuring the actual uptake of nicotine and smoke toxicants by suitable biomarkers of exposure) rather than relying on smoking machine-derived yields alone.

That compensation in smoking behaviour occurs is now widely accepted by all the important stakeholders in the field (public health representatives, regulators, scientists from governments, universities and industry). However, the extent of compensation (complete or partial) is controversial. While the general conclusion of the NCI Monograph 13 (U.S. Department of Health and Human Services, 2001) is that compensation is sufficiently complete for 'low tar' and 'ultra-low tar' cigarette smokers not to benefit from the nominal reduction in yield, other reviews of the epidemiological evidence relating lung cancer risk to type of cigarette smoked showed a clear reduction in risk associated with tar reduction and the switch to filter cigarettes (Lee, 2001), a reduction that is evident whether or not adjustment is made for amount smoked (Lee and Sanders, 2004). Furthermore, the role of nicotine (its pharmacological and sensory effects) and other factors (e.g., draw resistance of the cigarette, tar, flavour, conditioned behaviour, etc.) in

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compensational smoking are also not yet fully understood. Our review and meta-analysis provide additional relevant evidence for answering these questions.

2. Materials and methods

2.1. Structure of the review

The structure of the updated review is quite similar to that in our earlier review (Scherer, 1999). After presenting a general definition of compensation and giving the mathematical approach for quantifying the extent of compensation by a compensation index (CI), the relevant field and experimental studies are summarized. The studies have been classified into four categories:

- Cross-sectional studies with self-selected cigarette brands (no brand-switching).
- Brand-switching studies (forced or spontaneous). These studies are differentiated between those which consider a change in smoke yield levels of nicotine (or other smoke constituents) and those which investigate the effect of a reduction in nicotine content (RNC) in the tobacco blend. RNC cigarettes are designed to achieve a nicotine content in the blend which could not be compensated by the smoker and, therefore, should be evaluated separately.
- Compensation specifically for nicotine, including approaches such as (a) switching between cigarettes differing only in their nicotine yield, (b) smoking and simultaneous nicotine supplementation, (c) smoking and simultaneous administration of nicotine agonists/antagonists, (d) smoking behaviour in rapid and slow nicotine metabolizers, and (e) influence of polymorphic nicotine receptors on smoking behaviour.
- Compensation for factors other than nicotine.

Tables with detailed information on the individual studies of these classes are given in the Supplementary data (No 1–3). The main text of this review gives general descriptions, summaries and conclusions for each class of studies.

Compared to the previous review (Scherer, 1999), a new aspect is the inclusion of meta-analyses for suitable cross-sectional studies and brand-switching studies.

2.2. Identification of relevant studies

Published studies on compensational smoking used for meta-analysis, and further evaluations and interpretations of the compensation issue were obtained from the following sources: (i) the previous review (Scherer, 1999); (ii) literature search on PubMed focussing on literature since 1999; (iii) references cited in monographs (National Cancer Institute, 2001), books (Stratton et al., 2001; Institute of Medicine, 2011), US Surgeon General reports (US Surgeon General, 2010), and US FDA Guidelines (Food and Drug Administration, 2012) dealing with evaluating the effects of MRTPs. The literature search was conducted by one of us (G.S.). For identification of suitable studies from PubMed, a relatively broad search strategy was followed by combining the search terms 'smoking', 'cigarettes', and terms for the single biomarkers such as 'nicotine', 'cotinine', 'carboxyhaemoglobin', etc. A relatively large number of retrieved articles (about 250) were selected and studied for their suitability for inclusion in a meta-analysis. Essential for inclusion of a study was the provision of information on smoking machine-derived yields obtained with an established standard smoking regime (Baker, 2002) such as those defined by the International Standards Organization (ISO), the Federal Trade Commission (FTC), Massachusetts or Health Canada, as well as on corresponding suitable smoke uptake markers (biomarkers) (Scherer, 2006) or intake markers (mouth level exposure (MLE) data (Shepperd et al., 2006)).

2.3. Extraction of relevant data

From the studies retrieved from the various sources (see Section 2.2), the following pieces of information relevant for further evaluation (in particular meta-analyses) were extracted: Author, year and country of study and classes of brands smoked, categorized by machine-derived yields or yield bands. Additional data extracted, broken down by yield category were: Number of subjects and gender (if differentiated), daily cigarette consumption (CPD), smoking machine-derived yields of nicotine, tar, carbon monoxide (CO) and other smoke constituents, level of biomarkers for the uptake of nicotine, tar, CO and other smoke constituents. In case of brand-switching studies, the direction of switching (from higher to lower yield cigarettes of vice versa) and the class of study (either reduced nicotine content (RNC, see Section 2.1) or non-RNC) were assessed.

2.4. Quantifying the extent of compensation

Compensational smoking is defined as the adjustment of smoking intensity by the smoker in order to compensate for any changes in yield (or other properties) when switching from his/her usual cigarette to a new cigarette. This adjustment can either be accomplished by changing cigarette consumption per day (CPD), smoking topography (puff volume, frequency or duration) or inhalation pat-

Table 1
Events/milestones with potential impact on the issue of compensatory smoking.

Year	Publications	Conclusions and strategies having potential impact
2001	Smoking and tobacco control, Monograph 13: "Risks Associated with Smoking Cigarettes with Low Machine-Measured Yields of Tar and Nicotine" (National Cancer Institute, 2001)	It is concluded that smoking cigarettes with lower (machine-derived) tar and nicotine yields results in almost no reduction in risk, due to virtually complete compensation by the smoker
2001	Institute of Medicine Report (IOM) Report: "Clearing the smoke" (Stratton et al., 2001)	A strategy of tobacco harm reduction is proposed. The proposed evaluation of potentially reduced exposure products (PREPs) identifies any compensational smoking, and should thus lead to rejection of new products as PREP
2007	WHO Study Group on Tobacco Product Regulation 2007 (World Health Organization, 2007) and 2008 (World Health Organization, 2008) Burns et al. (2008) "Mandated lowering of toxicants in cigarette smoke: a description of the World Health Organization TobReg proposal" (Burns et al., 2008)	It is proposed to 'normalize' machine-derived yields not per cigarette, but to mg nicotine delivered per cigarette. This implicitly assumes complete (100%) compensation for nicotine
2009	US Government: Family Smoking Prevention and Tobacco Control Act of 2009, Public Law 111–31, 123 Stat. 1776 (June 22, 2009) (FSPTCA 911)	The FSPTCA 911 grants the Food and Drug Administration (FDA) authority to regulate the manufacturing, distribution, and marketing of tobacco products, including "modified risk tobacco products" (MRTPs)
2012	FDA: Draft Guidelines for testing of Modified Risk Tobacco Products (MRTPs) (Food and Drug Administration, 2012)	The testing of MRTPs follows largely the strategy outlined in the IOM Report (Stratton et al., 2001), thus purportedly leading to the rejection of products as MRTPs which show significant compensation upon use.