Human Smoking Behaviour in Comparison with Machine Smoking Methods:

A Summary of the Five Papers Presented at the 1995 Meeting of the CORESTA Smoke and Technology Groups in Vienna*

by

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SUMMARY

During the last months there have been extensive discussions, particularly in the United States, whether and to what extent data obtained by machine smoking using standardized methods (e.g. ISO, FTC, CORESTA) permit conclusions about the actual uptake of smoke constituents (nicotine, condensate, etc.) by a smoker. This topic was a major focus of interest at the meeting of the CORESTA Smoke and Technology Group in Vienna from 10th to 14th September 1995. A total of five studies were presented, four of which compared smoke yields obtained by standard machine smoking with actual yields obtained by human smoking. The fifth study investigated the effect of alternative puffing regimens and filter vent blocking on "tar" and nicotine yields of cigarettes. This paper summarizes the essential findings of the five studies.

Aufnahmemengen dieser Substanzen beim Raucher zu lassen. Dieses Thema bildete einen Schwerpunkt bei der Tagung der CORESTA Smoke and Technology Group vom 10. bis 14. September 1995 in Wien. Insgesamt wurden fünf Untersuchungen zu dieser Thematik vorgestellt, wovon sich vier mit dem Vergleich von Standardabrauchwerten und Rauchaussbeuten bei menschlichem Rauchen beschäftigten. In der fünften Studie wurde der Einfluß veränderter Abrauchparameter sowie des Blockierens der Filterventilationslöcher auf die Kondensat- und Nikotinausbeute von Zigaretten untersucht. In diesem Beitrag werden die wesentlichen Befunde der fünf Studien zusammenfassend dargestellt.

RESUME

Au cours des derniers mois il a été discuté vivement, particulièrement aux Etats Unis, la question à savoir si les rendements en nicotine, "goudrons", etc. déterminés par les méthodes de fumage normalisées (ISO, FTC, CORESTA) permettent de prédire les rendements générés par consommateurs individuels. Ce sujet a dominé la réunion commune des Groupes Fumée et Technologie du CORESTA qui s'est tenue à Vienne, Autriche, du 10 au 14 Septembre 1995. La session comportait cinq communications scientifiques; quatre communications ont comparé

ZUSAMMENFASSUNG

In den letzten Monaten gab es besonders in den USA intensive Diskussionen darüber, ob die nach Standardabrauchnormen (z.B. ISO, FTC, CORESTA) gewonnenen Werte für Nikotin, Kondensat usw. Rückschlüsse auf die

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les résultats obtenus par application de ces méthodes normalisées avec les valeurs établies pour le fumage humain. La cinquième communication a étudié l'influence des paramètres de fumage spécifiés et l'obturation des orifices de ventilation du filtre sur le rendement en "goudrons" et nicotine. Les résultats de ces communications seront résumés et présentés.

INTRODUCTION

For more than fifty years, great efforts have been directed towards developing standardized machine smoking methods for determining nicotine and particulate matter in the mainstream smoke of cigarettes (1, 8, 10), in order to compare the nicotine and condensate yields of different brands under precisely defined conditions (e.g. CORESTA, ISO, TIOJ, FTC methods) (2, 3, 9, 11, 12). In the meantime, some have been developed further to become national as well as international standards. For example, the Federal Trade Commission method (FTC) which is used in the United States has much in common with the method of the International Standard Organization (ISO) which is used widely throughout the world (Table 1). Both methods define a puff volume of 35 ml, a puff duration of 2 seconds and a puff frequency of 1 per minute. The two methods differ only in terms of butt length, air velocity and in the conditioning atmosphere for tobacco products (2, 3, 9, 13).

The data obtained by machine smoking procedures enable the consumers to compare the nicotine and "tar" yields of different brands. They are not intended to indicate the smoker's actual uptake of nicotine and "tar". Neverthe-

less, the differences between human smoking behaviour and machine smoking methods have increasingly become a focus of interest and have led to public debate, particularly in the USA. However, only a few studies have been published to date in which smoke yields are determined on the basis of standardized methods and compared with those yields obtained with individual smoking profiles recorded from smokers (4, 5, 6, 7).

This issue was discussed in five papers at the 1995 meeting of the CORESTA Smoke and Technology Group in Vienna. The most important results of these studies will be reviewed in the following.

VARIATIONS IN TAR, NICOTINE AND CARBON MONOXIDE DELIVERIES OBTAINED BY SMOKERS OF THE SAME BRAND

Bentrovato, B., A. Porter, M. Youssef and P.J. Dunn: Imperial Tobacco Ltd.

In their study, Dunn et al. recorded the individual puffing profile of 13 smokers (5 men, 8 women) who regularly smoked the same commercial king size filter brand. The standard machine smoking yields of this brand were 15.4 mg "tar", 1.43 mg nicotine and 16.0 mg carbon monoxide (CO). Puffing parameters such as puff volume, flow rate, puff duration, puff interval and puff number were determined in each individual once per day on four consecutive days by means of a cigarette holder containing a critical flow orifice. The mouth smoke deliveries were obtained by duplicating the averaged smoking profile of each individual on a 4-port smoking machine. In addition,

Table 1.
Conditions for standard machine smoking according to ISO and FTC.

Conditioning and smoking parameters	ISO	FTC
Conditioning temperature	22 ± 1 °C	24 ± 1 °C
Relative humidity (%)	60 ± 2%	60 ± 2%
Air velocity (mm/s)	200	Minimum required to remove smoke
Puff volume (ml)	35	35
Puff duration (s)	2	2
Puff frequency (puff/s)	1/60	1/60
Butt length	23 mm, but not less than length of filter tip + 8 mm and not less than overwrap length + 3 mm	23 mm or length of filter-overwrap + 3 mm (whichever is longer)

Table 2.
Puffing behaviour of smokers and duplicated mouth smoke deliveries of "tar", nicotine and CO as compared to the values using standard machine smoking methods (Bentrovato, B., A. Porter, M. Youssef and P.J. Dunn: Imperial Tobacco Ltd.).

Parameters	Means $\pm$ standard deviations (ranges)	
	Human smoking	Machine smoking (FTC)
Puff volume (ml)	46.9 $\pm$ 15.5 (18.5–64.3)	35
Mean flow rate (ml/s)	24.4 $\pm$ 4.2 (16.2–28.8)	17.5
Puff duration (s)	1.98 $\pm$ 0.66 (0.88–2.98)	2
Puff interval (s)	40.7 $\pm$ 16.9 (23.6–71.4)	58
Puffs per cigarette	10.8 $\pm$ 3.4 (6–18)	8.1
"Tar"(mg/cigarette)	18.0 $\pm$ 6.0 (8.7–26.4)	15.4
Nicotine (mg/cigarette)	1.50 $\pm$ 0.56 (0.80–2.46)	1.43
CO (mg/cigarette)	18.3 $\pm$ 5.9 (8.3–25.3)	16

cigarette butt lengths and alveolar carbon monoxide concentrations were measured.

The results are summarized in Table 2. Whereas quite consistent individual smoking patterns across the 4 smoking sessions were observed, the inter-individual variations were rather high. The average puff volume of the 13 smokers ranged from 18.5 to 64.3 ml. The observed mean puff volume of 46.9 ml was higher than the standard puff volume for machine smoking (35 ml). As observed in other studies, the average puff volume for all subjects decreased as a function of puff number. The average flow rate of 24.4 ml/s (range: 16.2–28.8 ml/s) was also higher than the standard flow rate of 17.5 ml/s for machine smoking. The average puff interval of 40.7 s (range: 23.6–71.4 s) was lower than that under standard smoking conditions (58.0 s). The mean puff duration was 1.98 s and equal to the standard parameter (2.00 s), but the inter-individual variations again were high (range: 0.88–2.98 s). The average number of puffs per cigarette was 10.8 (range: 6–18) and thus higher than under standard smoking conditions (8.1). The average butt length after human smoking was 32.8 mm (28–37.5 mm) compared to 28 mm after machine smoking.

The duplicated mouth smoke deliveries were 18.0 (range: 8.7–26.4) mg "tar"/cigarette, 1.50 (0.80–2.46) mg

nicotine/cigarette and 18.3 (8.3–25.3) mg CO/cigarette and thus were somewhat higher than the yields obtained by machine smoking (15.4, 1.43 and 16.0 mg/cigarette for "tar", nicotine and CO, respectively). The authors mention that smokers in smoking experiments tend to increase their puff number and reduce their puff intervals, leading to increased smoke yields. This has also been found by other investigators (14,15).

A very good correlation was found between the total volume of smoke taken from the cigarette and the mouth delivery of "tar" ($r^2 = 0.96$). However, when this regression was used for the machine-derived total volume of 283.5 ml/cigarette, a "tar" yield of 10.3 mg could be calculated, which is much lower than the standard yield of 15.4 mg. The authors suggest that for a given puff volume, humans tend to get considerably less "tar" than does a smoking machine. Only weak correlations were found between the alveolar CO concentration and the mouth CO deliveries ($r^2 = 0.44$) or the mouth "tar" deliveries ($r^2 = 0.43$). The authors state that the amount of smoke taken up or absorbed by the smoker will depend not only on the mouth level but also on the amount of mouth spill (smoke lost from the mouth before inhalation) as well as on the depth and duration of inhalation. Overall, the authors conclude from their results that the

Table 3.

Mean smoking behaviour parameters for three groups of smokers (*Reeves, N. and M. Dixon: British American Tobacco Co. Ltd.*).

Parameters	14 mg Product (N = 18)	9 mg Product (N = 21)	6 mg Product (N = 40)
Butt length (mm)	43.6	37.4	38.7
Puffs per cigarette	9.2	9.5	10.6
Puff interval (s)	38.2	40.7	32.3
Puff duration (s)	1.56	1.71	1.55
Puff volume (ml)	42.9	42.7	43.4
Integrated pressure (cm Wg.s)	35.4	34.9	37.9

average smoke deliveries were not very different from the standard machine-derived deliveries and that the amount of smoke absorbed by the smoker does not appear to be directly related to the amounts of smoke obtained from the cigarette. On the other hand, it should also be emphasized that there was a large inter-individual variation in smoke uptake although all smokers smoked the same brand.

THE MEASUREMENT OF HUMAN SMOKING BEHAVIOUR AND THE INFLUENCE OF MAIN STREAM SMOKE DELIVERIES ON CHANGES IN BEHAVIOURAL PARAMETERS

Reeves, N. and M. Dixon: British American Tobacco Ltd.

Reeves and Dixon used basically the same methodology as *Dunn* and coworkers to study the smoking behaviour of three groups of subjects who regularly smoked cigarettes with "tar" deliveries of 14 mg (18 participants), 9 mg (21 participants) and 6 mg (40 participants). However, instead of comparing the human smoking profile with the parameters for machine smoking, the three groups of smokers were compared with each other. In the smoking behaviour monitoring session, each subject smoked two cigarettes of his usual brand with a 20 min rest break in between. The smoking profile was measured with a pressure transducer. The means of the smoking behaviour variables for the three groups are shown in Table 3. Butt length, puff number, puff duration, puff volume and integrated pressure were similar in all three groups of smokers. The puff interval in the 6 mg "tar" group was 32.3 s, which is significantly lower than that for the 9 mg (40.7 s) and 14 mg "tar" group (38.2 s). The puff-by-puff analysis revealed a decline in the puff volume and puff

duration with increasing puff number. This is in agreement with results of *Dunn et al.* and other reports in the literature. *Reeves and Dixon* pointed out that, due to the reduction in tobacco rod filtration as the rod shortens, the "tar" delivery per puff increases with increasing puff number, as long as a constant puff volume is drawn. Therefore, puff-by-puff profiles are important in smoking behaviour analysis.

The results of this study seem to contradict findings of previous short-term switching studies which claim that low "tar" products are smoked more intensely than higher "tar" products (5-7). The authors speculate that smokers might be driven primarily by sensory clues such as taste, irritation, impact and mouthful and might therefore 'oversmoke' the low "tar" cigarette immediately after switching. However, over a period of time (e.g. weeks) of persistence with the low delivery product, the smoker may adapt in sensory and behavioural terms to the new product and the puffing parameters may revert towards their pre-switching values.

Unfortunately, no figures for the within-group variation of the smoking behaviour parameters are given. It can only be speculated that the variation is of similar size as in the other investigations.

THE CHEMICAL COMPOSITION OF MAIN STREAM CIGARETTE SMOKE GENERATED UNDER FTC / CORESTA AND ACTUAL HUMAN SMOKING (AHS) CONDITIONS

Djordjevic, M.V., J. Fan, and D. Hoffmann: American Health Foundation

A contrasting view is held by *Djordjevic et al.* These authors investigated 12 smokers who used to smoke low-

"tar"/low-nicotine (nicotine < 0.8 mg/cig) or medium-"tar"/medium-nicotine (nicotine 0.9–1.2 mg/cig) regular and mentholated cigarettes by a technique termed "Tobacco Smoke Inhalation Testing System" (TSITS), a method which is similar to those applied in the two studies reviewed above. In addition to the deliveries of "tar" and nicotine, those of tobacco-specific nitrosamines (TSNA) and benzo[a]pyrene (BaP) were also determined. The yields after actual human smoking (AHS) were compared with those after machine smoking according to the Federal Trade Commission (FTC) method.

The results are summarized in Table 4. Smokers of low- and medium-nicotine cigarettes drew larger puff volumes per cigarette than were drawn by the smoking machine operated according to the FTC protocol. As a result, the deliveries (mouth yields) of "tar", nicotine, TSNA and BaP were about 2–3-fold higher than the smoke yields obtained by machine smoking according to FTC. The authors state that their findings indicate that cigarette smokers compensate for nicotine. However, the authors also underline the necessity of increasing the number of subjects in order to evaluate the statistical significance of these findings and to support the conclusions drawn from them.

FTC YIELD AND NICOTINE UPTAKE IN SMOKERS

Byrd, G.D., J.H. Robinson, W.S. Caldwell and J.D. de Bethizy: R.J. Reynolds Tobacco Company

Byrd et al. chose a straight forward approach for comparing nicotine uptake in smokers with the FTC nicotine yields of the cigarettes smoked. They took advantage of improved analytical methods which allow the determination of almost total nicotine uptake (> 90%) by measuring nicotine and its major metabolites in the 24 h urine. Provided that the smokers are in steady-state condition with respect to their smoking, this noninvasive procedure permits the determination of actual nicotine uptake by smoking on a daily and per cigarette basis with the subjects smoking *ad libitum* with minimal impact on their daily routines. In this study, 33 smokers of at least 20 cigarettes/day took part. The subjects were selected according to the FTC "tar" yield category of the cigarettes they usually smoked: 9 subjects were 1 mg "tar" (1MG) cigarette smokers, 13 were ultra-low "tar" (ULT) smokers, 6 were full-flavor low "tar" (FFLT) smokers and 5 were full flavor (FF) smokers. The volunteers were required to smoke their usual brand of cigarette, record the number of cigarettes smoked, and collect all their urine over a 24 h period.

The group means and standard deviations of the FTC nicotine yields, the daily cigarette consumption and the

measured nicotine uptake are shown in Table 5. There was a broad range of daily nicotine uptake within each group: 1–22 mg for 1MG smokers, 4–42 mg for ULT smokers, 13–38 mg for FFLT smokers and 21–60 mg for FF smokers. The ranges were slightly narrower when the nicotine uptake per cigarette was calculated: 0.06–0.37 mg/cig for 1MG smokers, 0.16–0.82 mg/cig for ULT smokers, 0.37–0.86 mg/cig for FFLT smokers and 0.63–1.62 mg/cig for FF smokers. None of the group means for nicotine uptake per cigarette were significantly different from the FTC yields. The largest deviation for the ratio of nicotine uptake per cigarette and the FTC yield from unity (1.64) was found for the smokers in the 1MG group (Table 5). Despite the high inter-individual variability of the nicotine uptake within each group, there was a significant ($p < 0.05$) linear relationship of the nicotine uptake, both on a daily and per cigarette basis with the FTC nicotine yield.

The authors conclude from their results that the FTC method, while not necessarily predictive of nicotine uptake for an individual smoker, is predictive of the average nicotine uptake across "tar" categories and therefore useful for comparison of cigarettes by smokers. The advantage of this study is undoubtedly the fact that the smoking behaviour is not influenced by the experimental design. Its value is limited only by the rather low number of subjects.

THE EFFECT OF ALTERNATIVE PUFFING REGIMENS ON RELATIVE CIGARETTE PERFORMANCE

Borgerding, M.E. and L.S. Winkler: R.J. Reynolds Tobacco Company

Borgerding and Winkler determined mainstream smoke "tar" and nicotine yields under eight different puffing regimens which combine three levels each of puff volume (35, 45, 55 ml), puff duration (1.4, 1.7, 2.0 s) and puff frequency (30, 45, 60 s). A set of four commercial cigarettes in the "tar" categories 1MG, ULT, FFLT and FF as well as Kentucky reference cigarettes with "tar" yields of 1, 10, 15 and 22 mg were tested.

The most important result was that use of alternative puffing regimens did not affect the relative ranking of cigarette yields. The relative "tar" and nicotine yields remained approximately constant regardless of the puff regimen applied. As expected, absolute "tar" and nicotine yields increased when either puff volume increased (Figure 1) or when the time between puff decreased. Change in puff duration had only a minimal effect on the absolute smoke yields.

In an additional experiment, the influence of filter vent

Table 4.

Smoking profile and smoking yields after smoking low and medium nicotine cigarettes according to the FTC standard method and after duplicating actual human smoking (AHS) (Djordjevic, M.V., J. Fan and D. Hoffmann: *American Health Foundation*).

Data are means and ranges.

Parameters	Machine smoking (FTC)		Actual Human Smoking (AHS) ¹	
	low-nicotine cigarette	medium-nicotine cigarette	low-nicotine cigarette (8 Smokers)	medium-nicotine cigarette (4 Smokers)
Smoking profile				
Number of puffs	7.9	7.3	12 (7-15)	11 (7-14)
Puff volume (ml)	35	35	52 (45-63)	46 (43-48)
Total puff volume (ml)	276	256	606 (345-735)	470 (315-570)
Puff duration (s)	2.0	2.0	1.7 (1.2-2.0)	1.3 (1.1-1.5)
Puff interval (s)	58.0	58.0	28.5 (18-53)	33 (22-43)
Smoking yields				
*Tar ² (mg/cigarette)	9	16	30	28
Nicotine (mg/cigarette)	0.7	1.0	2.3-2.4	2.0
NNK ² (ng/cigarette)	92-144	162	280-332	301
B(a)P (ng/cigarette)	7.7	16.2	14.3-24.2	21.2

¹: Yields after actual human smoking (AHS) are taken from the text. Means and ranges are not always available.

²: 4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone

Table 5.
Comparison of FTC nicotine yield with nicotine uptake for four groups of smokers arranged by FTC yield category (Byrd, G.D., J.J. Robinson, W.S. Caldwell and J. Don de Bethizy: R.J. Reynolds Tobacco Company).
 Data are means $\pm$ standard deviations (ranges).

Group	Number of smokers	Cigarettes/24 h	FTC-nicotine yield ¹		Measured nicotine uptake		Ratio of measured to FTC yield
			mg/cig	mg/24 h	mg/cig	mg/24 h	
1 MG	9	35 $\pm$ 16	0.14 $\pm$ 0.01	4.8 $\pm$ 2.2	0.23 $\pm$ 0.11 (0.06 – 0.37)	9.1 $\pm$ 7.3 (1 – 22)	1.64 $\pm$ 0.82
ULT	13	37 $\pm$ 21	0.49 $\pm$ 0.06	18.7 $\pm$ 12.5	0.56 $\pm$ 0.23 (0.16 – 0.82)	19.2 $\pm$ 10.0 (4 – 42)	1.18 $\pm$ 0.53
FFLT	6	37 $\pm$ 14	0.67 $\pm$ 0.07	24.8 $\pm$ 8.3	0.60 $\pm$ 0.18 (0.37 – 0.86)	21.8 $\pm$ 9.4 (13 – 38)	0.89 $\pm$ 0.28
FF	5	34 $\pm$ 15	1.13 $\pm$ 0.15	38.1 $\pm$ 15.2	1.19 $\pm$ 0.43 (0.63 – 1.62)	37.3 $\pm$ 14.4 (21 – 60)	1.04 $\pm$ 0.34

¹ : Standard deviations in nicotine yields results from slightly different nicotine yields of the cigarettes in each "tar" category.

Effect of Alternative Puff Volumes

Figure 1. Effect of increasing puff volume on "tar" (a) and nicotine yields (b) of machine-smoked cigarettes. Brands A, B, C, D were cigarettes in the tar category 1 mg "tar" (1MG), ultra-low "tar" (ULT), full flavor low "tar" (FFLT) and full flavor (FF), respectively (*Borgerding, M. F. and L. S. Winkler: R. J. Reynolds Tobacco Company*).

Effect of Banding on "Tar" and Nicotine Yields

Figure 2. Effect of filter vent blocking on "tar" (a) and nicotine yields (b) of machine-smoked cigarettes. Smoking parameters were according to FTC specifications. Cigarettes were from the U.S. market. The eight brands represented two groups of four brands from two manufacturers. Each group of four cigarettes consisted of 2 ULT, 1 FFLT and 1 FF cigarette(s) (Borgerding, M. F. and L. S. Winkler: R. J. Reynolds Tobacco Company).

blocking on the "tar" and nicotine smoke yields was investigated under FTC machine smoking conditions. It was found that the relative ranking of cigarettes by smoke yields remained the same regardless of whether the filter vents were open or blocked. Of course, absolute smoke yields increased when the filter vents were blocked (Figure 2). This increase in smoke yields is mainly due to the large decrease in air dilution which is not out-balanced by the slight decrease in the number of puffs per cigarette.

CONCLUDING REMARKS

In the panel discussion, all authors agreed that there is a wide range in human smoking behaviour. The standard smoking methods were regarded as a useful tool for comparing the "tar" and nicotine yields of cigarettes. A change in the standard smoking parameters would not change the relative ranking of cigarettes according to their smoke yields. Therefore, machine-derived smoke yields are a source of indispensable information for the smoker - today and in the future.

It is obvious that a number of high yield cigarette smokers showed smoking behaviour parameters compatible with low smoke uptake, while a similar number of low yield cigarette smokers showed smoke uptakes comparable to those of high yield cigarette smokers. This finding together with the experimental conditions and the low number of subjects in most of the studies may be the cause for the at least partly contradictory results. Different positions were taken on the question whether or not smokers compensate for nicotine when smoking lighter cigarettes as suggested by DJORDJEVIC et al. In reality, the data presented here neither prove nor disprove the compensation hypothesis because the applied study designs do not specifically address this question. There was consensus that further research is needed for the investigation of the compensation hypothesis.

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