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Ultralow-Yield Cigarettes and Type of Ventilation: The Role of Ventilation Blocking

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HÖFER, I., R. NIL AND K. BÄTTIG. *Ultralow-yield cigarettes and type of ventilation: The role of ventilation blocking.* PHARMACOL BIOCHEM BEHAV **40**(4) 907–914, 1991.—Habitual smokers of perforation-ventilated cigarettes and of channel-ventilated cigarettes (18 male and 18 female subjects each; nicotine yield 0.1–0.3 mg, 0.2 mg, respectively) were compared with respect to different smoke exposure indicators and puffing behavior. The role of ventilation blocking was assessed by comparing normal lip contact smoking with smoking through a cigarette holder. The presmoking concentrations (plasma nicotine, cotinine, respiratory CO) were higher for channel-filter than for perforation-ventilated cigarettes, as were the pre- to postsmoking boosts (nicotine, CO) with normal lip smoking. Holder smoking resulted in lower boosts than lip smoking for the channel filter cigarettes, although the puffing behavior was considerably intensified. The boosts for perforation-ventilated cigarettes remained unchanged and were reached with only moderately intensified puffing behavior. The results indicate the importance of ventilation blocking in everyday lip smoking for channel-filter cigarettes, but not for conventional, perforated cigarettes.

Cross-sectional study Ventilation blocking Smoke exposure Respiratory carbon monoxide Plasma nicotine Plasma cotinine Puffing topography

THE low nicotine and tar deliveries of ultralow-yield cigarettes are generally achieved by means of smoke dilution using high-porosity cigarette paper, and perforation holes either in the filter part or directly in front of it. The machine-smoking yields of nicotine and tar can be considerably reduced with this type of cigarette, but in the human smoker, CO and nicotine absorption decrease less than would be expected on the basis of the machine-smoking yields (11). It is widely accepted that this partial upregulation is a result of adaptive changes of a greater volume of smoke being drawn into the mouth and deeper inhalation.

It has, however, also been suggested that this partial upregulation might be a result of blocking the ventilation holes, which reduces smoke dilution (17). In fact, blocking these holes mechanically does increase the machine yields (14,22). Ventilation blocking in everyday smoking has, until now, been investigated by observing human smoking behavior and analyzing filter stain patterns (12, 15–18). Recently, we attempted to control for possible ventilation blocking by comparing nicotine and CO absorption between smoking with natural lip contact and smoking through a cigarette holder, which eliminates any finger, lip, or saliva contact with the ventilation holes. With this approach, little, if any, evidence was obtained for ventilation blocking for cigarettes with perforation holes (11).

However, with cigarettes with another technique for smoke dilution, i.e., longitudinal air channels around the filter, ventilation blocking may indeed take place. With these cigarettes, compressing the filter increases the machine-determined yields of tar and nicotine, whereas this has only a marginal effect with perforation-ventilated cigarettes (12). Further, Hoffmann and coworkers (12) reported a considerably higher absorption of nicotine from channel-ventilated cigarettes than from cigarettes of similar nicotine yield with perforation holes. Cotinine concentrations were also considerably higher after channel-ventilated cigarettes, although the subjects had smoked fewer cigarettes per day than when smoking the conventional, perforated cigarettes. However, this switching study included only four subjects who had to switch from their habitual brands to ultralow-yield cigarettes, and it did not report on differences in puffing topography as possible compensation mechanisms.

The present study was done to examine whether these within-subject differences (12) could be confirmed when comparing habitual smokers of either channel-ventilated or perforation-ventilated cigarettes of comparable machine-determined yields. The study also included between-subject comparisons between the sexes, and within-subject comparisons between normal lip smoking and smoking through a flowmeter cigarette holder. The cigarette holder permitted the determination of smoke exposure while protecting the ventilation holes or channels from blocking and compression. The following dependent measures were considered: presmoking concentration of respiratory CO, plasma nicotine and cotinine as indicators of real-life smoke exposure, pre- to postsmoking boosts, puffing behavior to detect corresponding compensatory changes, and physiological and subjective effects of smoking. Additionally, subjects were required to follow a forced puffing procedure (30 puffs), to estimate the maximal smoke exposure.

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TABLE 1

SAMPLE CHARACTERISTICS

	Means						
	Channel		Perforation		ANOVA[1]		
Variable	F	M	F	M	Sex	Vent	S×V
N	18	18	18	18			
Age	30.2	32.8	26.1	35.2	9.51†	0.18	2.93
Weight (kg)	71.3	57.6	74.5	59.7	29.27‡	1.00	0.05
Height (m)	1.80	1.65	1.80	1.65	87.25‡	0.00	0.01
Start age	16.3	17.8	16.9	17.5	2.24	0.04	0.47
Years smoking	13.8	14.9	9.2	17.7	7.08†	0.27	4.20*
CPD	29.7	28.8	22.6	20.8	0.28	8.69†	0.03
Inh.depth	2.78	2.78	2.59	2.39	0.62	5.39*	0.63
Delay 1.cig	1.00	0.89	1.56	1.78	0.02	8.70†	0.36

[1]Entries; F-value (df= 1,68) and significance level: *$p \leq 0.05$; †$p \leq 0.01$; ‡$p \leq 0.001$.

TABLE 2

BRANDS, BRAND CHARACTERISTICS, AND NUMBER OF CONSUMERS

Brand	Nicot. mg	Tar mg	CO* mg	Ventil.* %	Males N	Females N
Channel Filter Cigarettes						
Barclay	0.2	1.0	0.9	85	17	18
Barclay 100	0.2	1.0	1.0	84	1	0
Means	0.2	1.0	0.9	85.0		
Perforated-Filter Cigarettes						
Muratti extra	0.3	3.0	5.4	54	5	11
R 6 ultra	0.2	2.0	5.0	68	3	4
Philip Morris ultra	0.1	1.0	2.5	70	5	0
Blue Ribbon ultra	0.1	1.0	1.3	81	4	0
Muratti extra 100	0.3	3.0	5.3	60	0	2
Select ultra legere	0.3	3.0	1.3	80	1	0
Select mild aroma	0.3	3.0	3.6	87	0	1
Means	0.2	2.3	4.3	63.3		

*Brand specific values for CO yield and degree of ventilation were kindly provided by the tobacco industry.

METHODS

Subjects

Seventy-two smokers (36 males, 36 females) of American Blend cigarettes with ultralow yields [machine-determined nicotine yield (2): 0.1–0.3 mg] participated in the study. One-half of the subjects habitually smoked cigarettes with longitudinal air channel ventilation filters (nicotine yield 0.2/0.9 mg with open/closed channels), and the other half smoked cigarettes with conventional, perforated filters. Subjects were recruited by newspaper advertisement (in part asking explicitly for ultralow-yield cigarette smokers); they were paid 100 Swiss Francs for participation. All subjects reported being in good health.

The sample characteristics are summarized in Table 1. The channel ventilation cigarette smokers reported a higher daily cigarette consumption (CPD), deeper inhalation (1 = none, 2 = low, 3 = high) and a shorter interval between getting up and the first cigarette of the day (0 = none, within 1, 2, or 3 hours, 4 = more) than the perforated-ventilation cigarette smokers. Furthermore, the female perforated-filter cigarette smokers reported a shorter smoking history than the remaining groups.

The perforated-filter cigarettes generally had a slightly higher nicotine, tar and CO yield, and a lower degree of ventilation than the channel ventilation cigarettes (cf. Table 2).

Biochemical Parameters

CO concentrations were determined with a CO analyzer (Beckman Instruments model 866) from expired tidal air samples collected in a 30-litre polyethylene bag during normal breathing. This method yields lower figures than the forced end-expiratory method [cf. (20,21)].

Nicotine and cotinine concentrations were determined at the Institut für Klinische Chemie, Universitätsspital Zürich, using a GC-MS method (6–8, 23) from 10-ml venous blood samples (reduced to plasma, stored at −80°C until analysis).

The amount of nicotine retained in the filter was determined with a GC-MS method (3) at the Laboratoire Cantonal, Epalinges. For the forced puffing condition, only the first and last butts were analysed.

Puffing Behavior

During smoking sessions with lip contact, puffing behavior (i.e., beginning and end of each puff) was recorded by the experimenter; during sessions with the cigarette holder, puffing behavior (i.e., changes in flow and pressure) was recorded automatically using a flowmeter cigarette holder [CGC Ltd., England, cf. (5)]. An off-line program determined for each smoking period the number of puffs, the average puff duration and interpuff interval, and the total puff duration, and for holder smoking, also the average puff volume, mean and peak flow, peak pressure, latency from beginning of puff to peak pressure, and total puff volume.

Heart Rate

Heart rate was recorded continuously via a photoplethysmogram (infrared transducer, fixed to the earlobe) and averaged for 1-minute intervals.

Subjective Ratings

Subjective need for smoking was rated on a 100-mm analog rating scale (no need/very high). On similar scales, subjects also rated smoking satisfaction (low/very high), strength (weak/strong) and taste (bad/good), and calming, activating, nervous and dizzy-making effects of smoking (not at all/totally). A more detailed description of the measures and of the procedure is available elsewhere (11).

Experimental Design and Procedure

Subjects came to the laboratory for two experimental sessions (2 hours each) on different days (usually 1–2 weeks apart). All sessions took place in the late morning or early afternoon, whenever possible at the same time of day for each subject. Subjects were not required to abstain from smoking. Each of the two sessions consisted of two experimental periods with a 40-minute rest period in between: the first smoking period called for natural puffing, i.e., smoking one (already lighted) cigarette of the habitual brand in the usual way; the second period required forced puffing, i.e., taking three puffs each on ten habitual brand cigarettes cut to half their length (tobacco rod; maximum 13 minutes), but without additional instructions (puff duration, intervals, etc.). The two sessions differed with regard to mouth

TABLE 3

PRESMOKING MEASURES

	Means[1]							
	Channel		Perforation		ANOVA[2]			
Variable	Lip	Holder	Lip	Holder	Vent	Contact	V×C	Other
Cigarettes on exp. day	M 10.8 F 8.9	7.7 9.9	8.1 6.4	7.9 7.2	2.16	0.79	2.53	S×C 8.19†
CO (ppm)	14.0	12.9	9.7	9.7	8.69†	1.66	2.08	
Nicotine (ng/ml)	14.2	12.9	8.5	8.4	14.63‡	1.57	1.10	
Cotinine (ng/ml)	283.5	291.2	178.3	173.6	14.38‡	0.04	0.69	
Heart rate (bpm)	79.8	79.4	80.8	81.7	0.74	0.04	0.22	
Smoking need	70.3	64.2	72.8	73.0	1.48	0.57	0.68	

[1]Entries: Arithmetic means for type of ventilation × contact condition, broken by sex if appropriate.
[2]Entries: F-value (df = 1,68) and significance level: *$p \leq 0.05$; †$p \leq 0.01$; ‡$p \leq 0.001$.
Abbreviations: S—Sex (M: males, F: females); V—Type of ventilation (channel, perforation); C—Contact condition (lip, holder).

cigarette contact: one session was carried out with direct lip contact (l) and the other one with a cigarette holder (h), in randomized order.

After being given general information concerning the experiment, subjects gave written consent to participate in the study. Sessions started with the collection of background information (general information, number of cigarettes smoked on experimental day), and the insertion of a catheter into a forearm vein. Then came the first experimental period with the natural puffing of a single cigarette, followed by a rest period of 40 minutes (questionnaire for smoking habits; reading), and after that, the second experimental period with forced puffing. Both experimental periods started with the taking of a blood sample for determination of nicotine/cotinine, a breath sample for CO analysis, the subjective rating of smoking need, and the registration of heart rate for one minute. They continued with the smoking period (natural or forced puffing) and the simultaneous recording of puffing behavior and heart rate and finished with the taking of the second blood sample, the second breath sample and subjective ratings of smoking quality and effects.

Data Analysis

The effects of the smoker's sex (S), type of ventilation (V, C—channel vs. P—perforation) and contact condition (C, l—lip vs. h—holder; within subjects) were analysed with full factorial ANOVAs and ANCOVAs (with CPD, years of smoking, and self-reported inhalation depth as covariates), computed separately for natural and forced puffing measures. All analyses were conducted with SPSSX or BMDP procedures on a Cyber 855 computer.

RESULTS

The results for the *presmoking measures*, obtained before the first smoking period (natural puffing), are summarized in Table

TABLE 4

PRE- TO POSTSMOKING BOOSTS FOR NATURAL PUFFING

	Means[1]							
	Channel		Perforation		ANOVA[2]			
Variable	Lip	Holder	Lip	Holder	Vent	Contact	V×C	Other
CO (ppm)	2.98	1.49	2.16	1.94	0.40	18.65‡	10.28†	
Nicotine (ng/ml)	10.67	3.33	5.22	4.25	6.97†	39.25‡	23.02‡	
Cotinine (ng/ml)	−0.2	−1.7	0.0	0.3	0.87	0.36	0.73	
Filter nicotine (mg)	M 1.55 F 1.05	1.43 0.90	0.86 0.84	1.03 0.96	9.66†	0.02	8.35†	S 7.56† S×V 9.66†

[1]Entries: Arithmetic means for type of ventilation × contact condition, broken by sex if appropriate.
[2]Entries: F-value (df = 1,68) and significance level: *$p \leq 0.05$; †$p \leq 0.01$; ‡$p \leq 0.001$.
Abbreviations: S—Sex (M: males, F: females); V—Type of ventilation (channel, perforation); C—Contact condition (lip, holder).

TABLE 5

PUFFING BEHAVIOR DURING NATURAL PUFFING

		Means[1]							
		Channel		Perforation		ANOVA[2]			
		Lip	Holder	Lip	Holder	Vent	Contact	V×C	Other
Flowmeter Independent Measures									
No. puffs	M	9.8	17.3	11.2	15.6	2.38‡	114.89‡	12.34‡	S×C 4.75*
	F	8.9	14.6	13.5	15.7				
Interval duration (s)		23.5	16.4	19.8	17.0	0.67	37.09‡	7.18†	
		Mean puff duration (s)	2.23	2.18	2.02	1.92	3.03	0.89	0.09
Total puff duration	M	21.8	40.0	21.3	29.2	0.04	66.68†	14.81†	S×V 6.77*
	F	18.8	28.4	27.5	29.5				S×C 9.78†
Butt length (mm)	M	7.7	8.6	11.3	10.1	0.50	0.35	4.54*	Sex 9.49†
	F	12.6	15.1	13.5	12.9				
Flowmeter Measures						Vent		Sex	Other
Mean puff volume (ml)	M		68.3		49.7	15.10‡		13.05‡	
	F		50.7		39.3				
Mean flow (ml/s)	M		28.7		27.0	6.09*		6.60*	
	F		26.8		20.4				
Peak flow (ml/s)	M		46.4		49.0	0.17		9.20‡	
	F		41.9		37.1				
Peak pressure (cm H_2O)	M		14.8		22.3	38.51‡		1.76	S×V 3.99*
	F		13.6		28.3				
Peak latency (s)			0.51		0.51	0.06		0.91	
Total puff volume (ml)	M		1136.1		743.6	13.08‡		14.26‡	
	F		732.2		608.8				

[1]Entries: Arithmetic means for type of ventilation × contact condition, broken by sex if appropriate.
[2]Entries: F-value (df=1,68) and significance level: *p≤0.05; †p≤0.01; ‡p≤0.001.
Abbreviations: S—Sex (M: males, F: females); V—Type of ventilation (channel, perforation); C—Contact condition (lip, holder).

3. The number of cigarettes smoked on the experimental day differed in a complex interactive way for sex and the lip/holder contact condition. However, this effect was not reflected by corresponding differences in the smoke exposure measures. The levels of respiratory CO, plasma nicotine and cotinine were higher in the smokers of channel filter than of perforated-filter cigarettes. The significance of these differences was maintained after controlling for CPD, years of smoking, and inhalation depth in the case of plasma nicotine [ANCOVA: F(1,64)=5.53] and cotinine [F(1,64)=5.28], but not for CO concentrations [F(1,64)=1.26; covariate CPD: F=33.81].

The *pre- to postsmoking boost measures* obtained for the period with natural puffing are shown in Table 4. Under normal lip contact conditions, the CO and nicotine deliveries of the channel-ventilated cigarettes were higher than those of the perforation-ventilated cigarettes and higher than with holder smoking. With holder smoking, both types of cigarettes delivered comparable amounts of CO and nicotine (t-tests; n.s.). The differences between lip and holder smoking were more pronounced for the channel filter than for the perforated-filter cigarettes. The latter delivered more CO and nicotine when smoked with lip than with holder contact (means); however, these differences did not reach significance (paired t-tests: n.s.). The results for the amount of nicotine retained in the filter were additionally differentiated by sex: Male channel filter cigarette smokers had the highest filter nicotine values; male perforated-filter cigarette smokers and female smokers had generally lower and rather comparable values. The channel-ventilated filters tended to retain more nicotine when smoked with lip contact, whereas the perforation-ventilated filter retained more when smoked through a holder.

The results for the *puffing behavior* variables for the first smoking period with natural puffing are summarized in Table 5. The flowmeter independent measures (number of puffs, puff intervals, total puff duration, butt length) differed in a complex, interactive way between ventilation type, lip/holder smoking and sex of the smoker. During lip smoking, the female perforated-ventilation cigarette smokers showed the most intensive puffing behavior (number of puffs, intervals, total puff duration), which was, however, not reflected in corresponding differences in butt length. During holder smoking, the male channel filter cigarette smokers showed the most intensive puffing behavior (number of puffs, total puff duration) and corresponding differences in butt length. The changes in puffing behavior from lip to holder smoking were affected by the type of filter and in part by sex. Channel filter cigarette smokers took more puffs when smoking through a holder, with a resulting higher total puff duration and shorter interval duration, but a longer butt length. Perforated-filter cigarette smokers changed their puffing behavior in the same direction, but to a much lower degree, and butt length differed in the expected direction. Male channel filter cigarette smokers increased their total puff duration from lip to holder smoking by more than 80 percent, whereas female perforated-filter cigarette

TABLE 6

PHYSIOLOGICAL EFFECTS AND SUBJECTIVE RATINGS

	Means[1]							
	Channel		Perforation		ANOVA[2]			
Variable	Lip	Holder	Lip	Holder	Vent	Contact	V×C	Other
Heart rate (bpm)	3.81	3.64	3.39	3.28	0.10	0.02	0.00	
Strength	M 50.6 F 64.3	21.2 8.8	42.4 49.9	22.8 29.9	0.00	97.16‡	12.81‡	S×C 4.38*
Taste	70.2	22.4	71.8	37.7	3.22	112.71‡	3.15	
Satisfaction	69.1	25.5	74.5	41.8	5.97*	128.02‡	2.60	
Activation	35.6	21.7	36.4	30.8	1.30	7.90†	1.22	
Calming	46.3	30.0	51.1	42.7	3.36	9.06†	0.58	
Nervousness	17.1	27.4	13.7	18.6	2.46	4.69*	0.46	
Dizziness	16.8	7.0	13.6	13.5	0.16	3.54	3.35	

[1]Entries: Arithmetic means for type of ventilation × contact condition, broken by sex if appropriate.
[2]Entries: F-value ($df=1,68$) and significance level: *$p\leq 0.05$; †$p\leq 0.01$; ‡$p\leq 0.001$.
Abbreviations: S—Sex (M: males, F: females); V—Type of ventilation (channel, perforation); C—Contact condition (lip, holder).

smokers increased theirs by less than 10 percent. The flowmeter holder session further revealed that the channel filter cigarettes were smoked with greater mean and total puff volumes and lower peak pressures than the perforated-filter cigarettes. The higher flowmeter measures (volumes and flows) for males than for females are consistent with the shorter butt lengths observed for male smokers, indicating that males had burnt more tobacco.

The *physiological effects and subjective ratings* for natural puffing are summarized in Table 6. Heart rate generally increased over the smoking period, but this was independent of filter type or contact condition. When smoked with normal lip contact, both types of cigarettes earned comparable subjective ratings. Smoking through a holder generally lowered the ratings for strength, taste, satisfaction, activating and calming effects, and increased the ratings for nervousness. The reduction in strength was more pronounced for the channel filter cigarettes (especially for female smokers) than for the perforated-filter cigarettes. Similar holder-lip differences in the means can be seen for the other rating variables, especially taste, satisfaction and dizziness, although these differences did not reach statistical significance.

The main results for *forced puffing* (30 puffs) are summarized in Table 7. Under holder smoking conditions, the channel filter and the perforated-filter cigarettes delivered comparable amounts of CO and nicotine (*t*-tests, n.s.), whereas under lip smoking conditions, the channel filter cigarettes had higher deliveries than the perforated-filter cigarettes (*t*-tests: $p<0.001$). For both types of cigarettes, the boosts were higher with lip than with holder smoking. The differences were more pronounced for channel-ventilated cigarettes, as was observed under natural puffing; however, with forced puffing, the lip-holder difference also reached significance for the perforated-filter cigarettes (paired *t*-test: $p=0.007$, $p=0.02$ for CO, nicotine). With respect to the amount of nicotine retained in the filter, the lip-holder differences were small for the perforated-filter cigarettes and pronounced for the channel filter cigarettes, so that the highest values were observed for (male) channel filter cigarette smokers under lip smoking conditions.

The butt lengths of the perforated-filter cigarettes were equal after lip and holder smoking, whereas the butts of the channel filter cigarettes were longer after holder than after lip smoking, indicating that more tobacco was burnt during lip than during holder smoking. The volume, flow and pressure measures (referring to individual puffs) showed similar sex and type of filter ventilation differences to those observed for natural puffing.

Comparing forced with natural puffing, the puffing behavior variables referring to individual puffs were generally reduced under forced puffing (all $ps<0.01$ in 4-factorial ANOVAs, except for mean puff volume, peak pressure; not computed for butt length and filter nicotine). As expected, the total puff duration and volume, and the boosts were higher under forced than under natural puffing. However, these increases, except the increases in total puff volume, were less pronounced than the increases in the number of puffs. For channel filter cigarettes under lip and holder smoking, and perforated-filter cigarettes under lip and holder smoking, the relation of forced to natural puffing amounted for the number of puffs to 3.21, 1.88, 2.43, and 1.91; for total puff duration to 2.78, 1.68, 2.16, and 1.80; for total puff volume to 1.94 and 2.02; for the CO boosts to 2.47, 1.67, 1.96, and 1.65; and for the nicotine boosts to 1.57, 1.77, 1.39, and 1.38.

DISCUSSION

The main purpose of the present study was to compare the smoke exposure in habitual smokers for perforation-ventilated and channel-ventilated cigarettes. The results indicate a higher smoke exposure with channel-ventilated cigarettes during lip smoking, although their machine-determined yields (2) are comparable to or even lower than those of the considered perforation-ventilated cigarettes. This holds for the indicators of long-term smoke exposure from everyday smoking, as assessed in the laboratory with the presmoking measures, as well as for the acute boosts due to the subsequent lip-smoking of a single cigarette. The differences in nicotine exposure were generally the most pronounced, culminating in a nicotine boost from channel-

TABLE 7

FORCED PUFFING

		Means[1]				ANOVA[2]			
		Channel		Perforation					
		Lip	Holder	Lip	Holder	Vent	Contact	V×C	Other
Pre- to Postsmoking Boosts									
CO (ppm)		7.36	2.49	4.24	3.20	3.97*	0.40	26.27‡	
Nicotine (ng/ml)		16.70	5.89	7.25	5.87	15.22‡	42.76‡	25.50‡	
Filter nic.[3] (mg)	M	0.57	0.28	0.24	0.22	47.82‡	59.83‡	61.83‡	Sex 21.23‡
	F	0.36	0.19	0.16	0.19				S×V 4.60*
									S×C 7.82†
Puffing Behavior									
Flowmeter Independent Measures									
Interval duration (s)		17.0	12.1	17.9	14.2	5.70*	169.45‡	2.95	
Mean puff duration (s)		1.89	1.90	1.77	1.75	1.40	0.00	0.12	
Total puff duration (s)	M	61.5	64.9	52.1	54.8	1.48	0.13	0.06	Sex 4.06*
	F	51.4	50.0	53.4	51.1				
Butt length[3] (mm)		13.8	17.7	15.9	15.5	0.01	25.88‡	38.16‡	
Flowmeter Measures						Vent		Sex	Other
Mean puff volume (ml)	M		69.7		51.6	15.35‡		18.66‡	
	F		50.1		38.9				
Mean flow (ml/s)			32.5		26.7	10.7†		7.08†	
Peak flow (ml/s)			49.1		47.9	0.14		11.73‡	
Peak pressure (cm H_2O)	M		14.4		23.3	52.69‡		1.45	S×V 5.18*
	F		12.5		29.5				
Peak latency (s)			0.48		0.49	0.01		0.04	
Total volume (ml)	M		2113		1559	15.20‡		14.09‡	
	F		1505		1177				

[1]Entries: Arithmetic means for type of ventilation × contact condition, broken by sex if appropriate.
[2]Entries: F-value (df=1,68) and significance level: *$p \le 0.05$; †$p \le 0.01$; ‡$p \le 0.001$.
[3]Means referring to mean (butt 1, butt 10).
Abbreviations: S—Sex (M: males, F: females); V—Type of ventilation (channel, perforation); C—Contact condition (lip, holder).

ventilated cigarettes that was twice as high as from perforation-ventilated ones, whereas the differences in CO measures were less clear-cut. For the presmoking concentrations, this might be caused by the differences in cigarette consumption. In addition, the lower CO yields of the channel-ventilated cigarettes should be taken into consideration.

These between-subjects differences confirm the within-subject comparisons of switching between channel- and perforation-ventilated cigarettes, as reported by Hoffmann and coworkers (12). They observed higher nicotine boosts and cotinine concentrations after two weeks with channel-ventilated as compared to perforation-ventilated cigarettes, but no differences in CO boosts and COHb concentrations. However, the reported nicotine boosts for the channel-ventilated cigarettes (26.1 ng/ml) seem very high, even when considering a higher active nicotine delivery (1, 9–11, 13), whereas the boosts for the perforation-ventilated cigarettes (6.6 ng/ml) are comparable to (nondeprived) boosts from low-yield cigarettes (10,11). The preceding 4-hour deprivation period, which might have intensified the puffing behavior and thus the boosts (19,24), should have affected both types of cigarettes.

Higher boosts were reached with lip-smoked channel filter cigarettes, in spite of the fact that the puffing behavior appears somewhat less intensive than for the perforation-ventilated cigarettes (number of puffs, total puff duration for females). Of course, it cannot be excluded that channel filter cigarette smokers took "stronger" puffs with respect to volumetric parameters. The differences in butt length also suggest that the channel filter cigarette smokers puffed more effectively, i.e., that they burned more tobacco.

On the other hand, when smoking through a holder, i.e., with fully functioning ventilation, the CO and nicotine boosts were very similar for both types of cigarettes, although the channel filter cigarettes were smoked more intensively, at least by males (number of puffs, total duration, butt length), and by both sexes with higher mean and total puff volumes. The low peak pressure values observed for holder-smoked channel filter cigarettes correspond with the low draw resistance values for these cigarettes (12).

With respect to ventilation blocking and other compensational mechanisms, the differences between lip and holder smoking are of special interest. The perforation-ventilated cigarettes showed only modest differences, whereas the differences for the channel filter cigarettes were considerably greater, especially for the nicotine boosts. To the extent that these higher boosts during lip smoking are not reflected in corresponding intensified puffing behavior (or inhalation depth), they suggest ventilation blocking. The perforated-filter cigarette smokers reached similar boosts under both conditions by moderately intensifying their puffing behavior during holder smoking (number of puffs and total puff duration for males, butt length changing in the same direction). These results confirm that, for perforation-ventilated cigarettes, ventilation blocking is of minor importance (11). The smokers of channel-ventilated cigarettes intensified their puffing behavior under holder smoking conditions much more pronouncedly (number of puffs, puff frequency, total puff duration: increases up to 80% in males). However, these increases in puffing behavior resulted in a lower amount of burnt tobacco and in lower boosts, i.e., puffing was less effective. This mismatch in puffing behavior and boosts may indicate that with normal lip contact, the smokers at least partly blocked the ventilation channels, thus reducing smoke dilution.

The individual magnitudes of the differences in CO and nicotine boosts between lip and holder smoking may give some information about the prevalence of blocking. Assuming as criterion an increase in nicotine boost of 2 ng/ml or more from holder to lip smoking, 86 percent of the channel filter cigarette smokers and 33 percent of the perforated-filter cigarette smokers would be classified as "blockers." Assuming a minimal difference of 1 ppm for the CO boosts, 58 percent of the channel and 22 percent of the perforated-filter cigarette smokers would be classified as blockers. Compared to a blocking prevalence between 50 to 60 percent derived from the analysis of filter stain patterns by Kozlowksi (15,16), the prevalence of blocking in our study is considerably lower in the perforated-filter and considerably higher in the channel filter cigarette smokers. The conclusion that most channel filter cigarette smokers are blockers is supported by other results: The presmoking plasma cotinine concentrations of our channel and perforated-filter cigarette smokers differ in a similar way to those reported for blockers vs. nonblockers [369 vs. 209 ng/ml, (15)]. Presmoking CO levels differ in a similar way [31.9 vs. 15.4 ppm, (15)], assuming that the generally used end-expiratory CO measures are about twice as large as the tidal CO measures used in the present study (unpublished data from our laboratory). Furthermore, blockers have been reported to smoke more cigarettes per day and with a shorter delay in the morning, as was also the case for the channel filter cigarette smokers in the present study. This might indicate that channel filter cigarette smokers are more dependent smokers and have selected a brand with a higher real (nicotine) delivery. Taking into consideration the mentioned relationship of end-expiratory and tidal CO measures, the CO boosts for the perforation-ventilated cigarettes and for the holder-smoked channel filter cigarettes correspond to CO boosts from ultralow-yield cigarettes with fully functioning ventilation [4.32 ppm, (25)], and those for the lip-smoked channel filter cigarettes correspond to boosts with 50 percent blocking [6.44 ppm, ad lib puffing; (25)].

The relatively small heart rate increases in our study, which were independent of type of ventilation or contact condition (i.e., nicotine boost), as opposed to those reported by Hoffmann and coworkers (12), might be an effect of the widely documented acute tolerance in nondeprived smokers (19).

The forced puffing procedure showed widely similar results to those obtained with natural puffing. The boosts from lip-smoked channel filter cigarettes were highest, and considerably higher than with holder smoking. For the perforated-filter cigarettes, the differences between lip and holder smoking were more obvious than under natural puffing. A comparison between forced and natural puffing further revealed that forced puffing was associated with down-regulation mechanisms.

As a last point, it seems of some interest to speculate on the actual nicotine yield of the channel-ventilated cigarettes. When evaluated according to their boosts, they are equivalent to perforation-ventilated cigarettes with a machine-determined yield of about 0.5 to 0.8 mg (11). This estimation seems consistent with a machine yield of 0.5 mg nicotine determined according to the currently used Coresta method No. 22 (4). The higher yield on the basis of the presmoking concentrations is likely to be a consequence of the high self-reported daily consumption in the investigated group.

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