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Smoking Multiple High- Versus Low-Nicotine Cigarettes: Impact on Resting Energy Expenditure

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The thermic effect of smoking multiple cigarettes varying substantially in nicotine yield was investigated. Three treatments were imposed: nonsmoking at baseline, smoking six low-nicotine (0.8 mg nicotine) cigarettes (LOW), and smoking six high-nicotine (1.74 mg nicotine) cigarettes (HIGH). An initial increase of 6.8% in resting energy expenditure (REE) above baseline REE occurred after consumption of two consecutive cigarettes for both the HIGH and LOW treatments. With consumption of more cigarettes, the peak increase for the HIGH treatment was 9.3%, significantly greater than the peak of 5.9% for the LOW. Averaged over 2 hours, the HIGH treatment significantly increased REE by 6.9% and the LOW treatment significantly increased REE by 5.2%. Expired carbon monoxide (CO) measurements indicated that LOW cigarettes were smoked more aggressively than HIGH cigarettes. It was concluded that, initially, the nicotine yield of cigarettes is not an important influence on the thermic effect of smoking. But over a longer period and after multiple cigarettes, the nicotine yield may become an important influential factor.

WEIGHT GAIN OCCURS frequently following cessation of cigarette smoking.[1-4] An acute but variable thermic effect of smoking has been observed,[5-10] and loss of this effect could play a role in weight gain. Some variability in the acute thermic effect among subjects may be due to differences in study design: failure to have subjects fast or abstain from smoking before testing, failure to adequately familiarize subjects with the testing environment and experimental apparatus, failure to recognize and minimize stress-related arousal, failure to control for effects of the menstrual cycle, and differences in the length of measurements made after smoking and in the smoking history and body composition of subjects.[6,11-15]

The nicotine yield per cigarette also could be a factor that influences the thermic effect, but the impact of inhaling smoke from multiple cigarettes differing substantially in nicotine yield has not been investigated. Perkins et al[16] found that administering nicotine via an aerosol nasal spray with a strength of 15 μg/kg (the nicotine dose received from a typical American-made cigarette) resulted in a significantly lower thermic effect as compared with a dose of 30 μg/kg. It is not known whether smoking cigarettes with a similar disparity in nicotine yield would produce the same results with regard to changes in the resting energy expenditure (REE).

A major difference in delivering nicotine via nasal spray versus cigarette smoke is that the nasal spray dose cannot be effectively altered by the subject, whereas the dose obtained by smoking cigarettes can be. There is evidence to support the notion that blood nicotine levels are affected more by the manner in which a cigarette is smoked (the intensity) than by the nicotine yield.[17-22] However, it is unknown whether the intensity of smoking rather than the nicotine yield per cigarette will also dictate the degree of impact on REE, especially when multiple cigarettes are consumed. Thus, the purpose of the present study was to determine the thermic effect of smoking multiple cigarettes with markedly differing nicotine yields.

SUBJECTS AND METHODS

Subjects

Subjects were recruited by distribution of flyers and advertisement in the local newspaper. A stipend was paid for participation. Study participants were men in good health, aged 18 to 65 years, who smoked cigarettes regularly for at least 1 year. All subjects

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were examined by a physician and were excluded from participation if cardiopulmonary disease, diabetes mellitus, or thyroid disease were detected. Subjects could not be taking medication known to interfere with metabolism such as antihistamines, decongestants, or sedatives. Eighteen subjects were accepted for study. Of these, two were excluded because they were unable to comply completely with the study protocol. Table 1 lists subject characteristics.

Equipment and Measurements

Indirect measurement of metabolic rate was performed using a Sensormedics 2900 Z open-system metabolic cart (SensorMedics, Anaheim, CA), which continuously measures oxygen consumption and carbon dioxide production, reported as 1-minute means. From these measurements, the respiratory exchange ratio and kilocalories consumed per minute were calculated, reflecting the REE. Gas was collected into a well-fitted, full-face dilution mask that continuously drew fresh air past the subject. Resting metabolic rate measurements were taken in a darkened room, with the subject seated in a comfortable recliner and listening to the music of his choice. No one was in the room except the subject and a technician, who monitored the cart and the subject to ensure he remained awake but quiet.

Cigarettes smoked were either high-nicotine 2R1F ([HIGH] yielding 1.74 mg nicotine and 22.0 mg carbon monoxide [CO] per cigarette by Federal Trade Commission testing, Kentucky Tobacco and Health Research Institute, University of Kentucky, Lexington, KY)[23] or low-nicotine 1R4F ([LOW] yielding 0.8 mg nicotine and 11.6 mg CO per cigarette). Subjects were instructed to smoke in their normal manner, as they wished, to within 5 mm of the filter. Ten minutes were allowed per cigarette smoked.

Before participating in the first research session, subjects signed an informed consent document approved by the University Human Subjects Committee. Subjects were then shown the laboratory and the metabolic testing equipment and underwent a "dry run" to allow them to become familiarized with the feel of the equipment and to make certain they were aware of all expectations. At this time, subjects also underwent assessment of body fatness, determined by the multiple-site skinfold technique.[24]

Testing Protocols

Subjects arrived at the laboratory early on the day of testing, having fasted (but allowed water ad libitum) and abstained from cigarettes and vigorous exercise for the previous 12 hours. An expired CO sample was obtained, and decisions were made regarding the degree of compliance with the pretest protocol. Subjects were excluded from testing on a given day if the respiratory exchange ratio was greater than 0.85 or if expired CO was greater than 2.5% (16 ppm) on a CMD/CO carbon monoxide monitor (Spirometrics, Auburn, ME). Subjects then relaxed in a comfortable recliner chair for the next 45 minutes before testing began. This allowed a return to baseline REE before initiating the test. The sequence in which the protocols were performed was randomized.

Protocol 1 (resting baseline). REE was measured for 30 minutes, followed by a 20-minute break during which the subject continued to sit quietly without wearing the mask but did not smoke cigarettes. For the next 2 hours, REE was measured for 20-minute periods alternating with 10-minute periods of sitting quietly without wearing the mask.

Protocol 2 (LOW cigarettes). REE was measured for 30 minutes, followed by a 20-minute break during which the subject continued to sit quietly without wearing the mask and smoked two 1R4F (0.8 mg nicotine) LOW cigarettes. For the next 2 hours, REE was measured for 20-minute periods alternating with 10-minute periods during which one cigarette was smoked. A total of six cigarettes were consumed.

Protocol 3 (HIGH cigarettes). Protocol 3 was identical to protocol 2, except for the use of HIGH cigarettes (2R1F, 1.74 mg nicotine).

Table 1. Descriptive Characteristics of the Subjects (N = 16)

Characteristic	Mean ± SD
Age (yr)	41 ± 11
Height (cm)	177.7 ± 8.0
Weight (kg)	80.9 ± 16.7
Body fat (%)	19.5 ± 5.0
Pack-years	28.5 ± 18.5

Smoking Intensity

In an attempt to obtain a gross assessment of smoking intensity, exhaled CO was measured after smoking the first two cigarettes and then after each of the four remaining cigarettes.

Statistical Analyses

One-way ANOVA was used to test for significant differences in energy expenditure during the 30-minute daily baseline measurements across the three protocols. To test for the effects of the smoking treatments, repeated-measures multivariate ANOVA was used. There were two within-subject factors: treatment (HIGH, LOW, and baseline–nonsmoking), and a five-level repeated smoking measurement, representing REE after smoking the first two cigarettes, then the third, fourth, and so on. Post hoc analysis consisted of Bonferroni simultaneous t tests with a family α of .05.

RESULTS

Expired CO was similar for both HIGH and LOW cigarettes throughout the two protocols (Fig 1). This suggests that LOW cigarettes, as expected, were smoked more aggressively, because the CO yield of HIGH cigarettes (2R1F) was twice that of LOW cigarettes (1R4F), 22.0 versus 11.6 mg per cigarette, respectively.

During the resting baseline treatment (protocol 1), no significant change in REE was detected across the 2-hour (plus initial 30-minute) measurement period. There also were no significant differences across treatments in the 30-minute daily baseline REE measured during protocols 1, 2, and 3. Overall, there was a significant increase in REE relative to the resting baseline protocol as a result of both the LOW and HIGH treatments. LOW and HIGH treatments did not differ in absolute terms, but there was a significant interaction between these two treatments and time, the effect of which is seen in Fig 2.

Smoking significantly increased REE by 6.8% above the resting baseline level (Fig 2). The effect was the same for both HIGH and LOW cigarettes. Following the initial increase in REE after smoking HIGH and LOW cigarettes, REE declined slightly. The decline continued when smoking LOW cigarettes, plateauing at an increase of 4.2% above the resting baseline. This was eventually followed by an increase in REE that approached the initial peak (5.9%).

A different trend in REE was observed for HIGH cigarettes. Following the initial peak and then decline, REE increased progressively, ultimately reaching a 9.3% increase above baseline. The latter effects on REE were

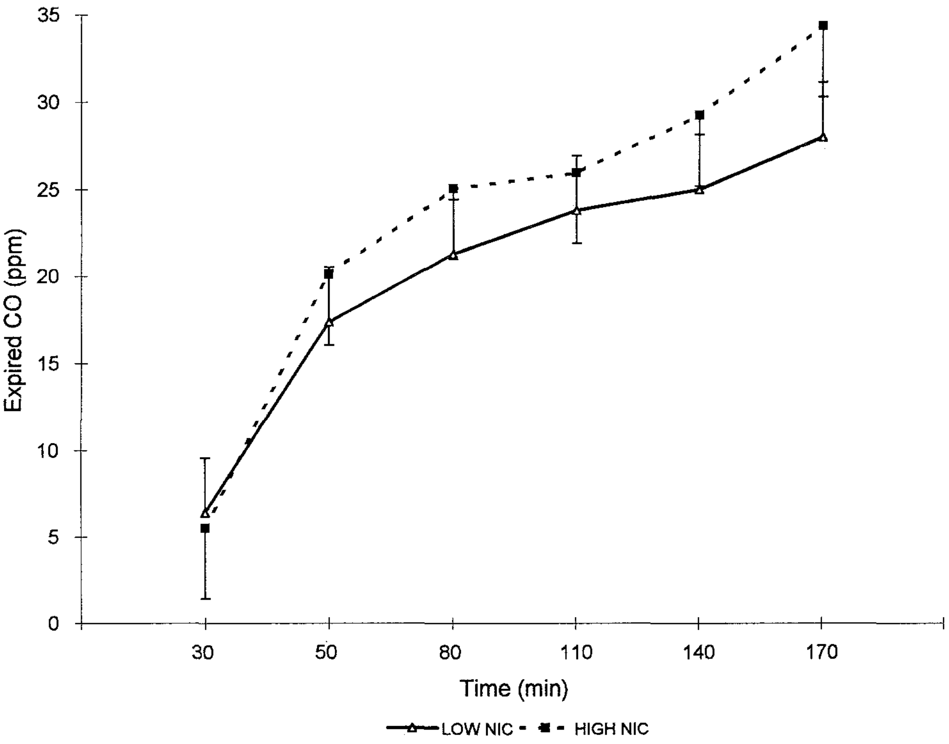

Fig 1. Expired CO measurements for multiple LOW (△) versus HIGH (■) cigarettes. Data are the mean ± SEM.

significantly greater ($P < .05$) for HIGH as compared with LOW cigarettes.

DISCUSSION

The initial increase in REE of 6.8% as a result of smoking two cigarettes is consistent with previous reports[6,7] and with our earlier findings.[8-10] After smoking three cigarettes, the change in REE was essentially the same for both HIGH and LOW cigarettes. These findings support our hypothesis but conflict with findings previously reported by Perkins et al,[16] who found nearly double the response when administering a 30-μg/kg dose of nicotine versus 15 μg/kg.

We attribute our findings to the aggressive smoking of the LOW cigarettes and/or sluggish smoking of the HIGH cigarettes. Carboxyhemoglobin and expired CO are strongly correlated, and the latter offers the advantage of a noninvasive measurement of CO.[25] Expired CO data indicate that

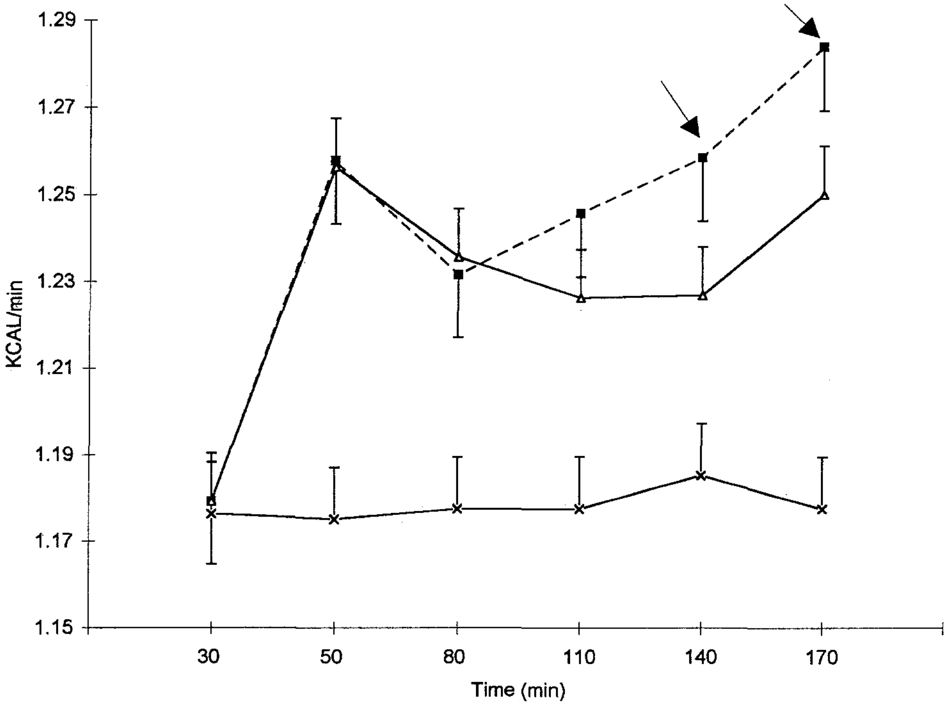

Fig 2. REE during resting baseline (X, nonsmoking) and during treatment with multiple LOW (△) versus HIGH (■) cigarettes. Arrows indicate significant differences between LOW and HIGH cigarettes, occurring at the fifth and sixth cigarettes. Data are the mean ± SEM.

the LOW cigarette, because of its low CO yield, was smoked nearly twice as aggressively as the HIGH cigarette, which has a nearly twofold CO yield. Addition of puff frequency and puff length (a reflection of puff depth) would have added to the strength of the CO data. Such data were not planned for the present study, but need to be included in future investigations of this nature. Even so, it seems reasonable that chronic cigarette smokers would smoke LOW cigarettes aggressively following a 12-hour abstinence. HIGH cigarettes, on the other hand, could be smoked less aggressively and still offer a satisfying nicotine yield.

The data imply that after smoking three cigarettes, a similar blood nicotine level may have been achieved with either the HIGH or LOW cigarettes despite the large difference in nicotine yields. However, there are no blood nicotine values available to document this. As the study progressed, a greater impact of the HIGH cigarettes on the thermic effect became evident. It is possible that consuming HIGH cigarettes every 20 minutes exceeded the need and/or desire for nicotine, which was not compensated for by a sufficiently reduced smoking intensity. Perhaps there is a minimal level of aggressiveness that chronic smokers apply to the act of smoking regardless of the need or desire for nicotine.

With regard to differences in the thermic effect of smoking found among previously published research studies, it is unlikely that differences in the nicotine yield of cigarettes consumed was an influential factor. This is because the cigarettes used in previous studies do not differ substantially from typical American-made cigarettes with respect to nicotine yield. Moreover, smoking intensity among subjects could easily overwhelm subtle differences in the nicotine yield of cigarettes.

It is concluded that, initially, the nicotine yield of cigarettes smoked may not influence the thermic effect, even though the nicotine yield varies substantially. However, continued repeated smoking of HIGH cigarettes in a compressed time frame eventually exerts a significant impact on REE—greater than that observed when smoking LOW cigarettes. Despite the eventual impact of HIGH cigarettes, the applicability of this finding as a means of accounting for a meaningful portion of the variability found in the thermic effect of smoking in previous studies is doubtful.

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