Background and Hypotheses

In a previous paper (1) the decline of alcohol levels over time as determined by breath and blood was investigated as well as its variability. This work was extended to the present study when the considerable variation in blowing practice during breath testing was observed. Besides differing interpretations of full lung exhaustion in directions to the subject to exhale completely, some subjects do not follow these directions for other reasons. For example, a person under the influence will often not be able to exhale completely or may deliberately be noncooperative. Those with disease conditions may not be able to follow directions properly. For this reason it was decided to investigate the effect of limited expiration in a breath-taking situation.

In view of the exhalation process it is hypothesized that under conditions of short exhalation time one should get a reduced alcohol level compared to the normal alveolar breath obtained after a full exhalation. Two main processes are involved. One is that during full exhalation gas remaining deep in the lungs before expulsion has an opportunity to rise in temperature and can thus support a larger amount of diffused alcohol vapor emanating from the alveolar surface. The other is that the alcohol vapor reaching this gas has a longer time available for diffusion and increased concentration approaching maximum. It is predicted that the longer the exhalation time, the closer the alcohol level will get to the asymptote reached with complete diffusion and equilibrated lung temperature. If exhalation time is reduced, the processes of diffusion and temperature change are not permitted to approach so closely to that asymptote and the observed breath alcohol will thus be lower.

On the other hand, in cases where normal exhalation time is short, then extension of the two processes by one means or other will bring the observed alcohol level closer to that asymptote. Breath-holding, which extends both processes, is therefore predicted to increase the alcohol level observed, and this increase should be greater, the shorter the normal exhalation time when taking a standard breath. In cases of reduced exhalation time, say to half, one would then predict that the alcohol level associated with large amounts of alcohol will suffer a greater decline under the half-breath condition than lower levels. If there is an approximately proportional reduction for all observed alcohol levels due to insufficient diffusion time or not enough time to change temperature (since the time and temperature differences are small), this proportion should show up as a greater absolute decline for higher alcohol levels than low. The consequence is that the slope of the line describing reduction of alcohol over time should be less for the half-time breath than for the full-time breath. Further, the slope of the breath which is held and then exhaled for a period equivalent to the half-time breath should give alcohol levels considerably higher than those of the standard half-time breath. It is not easy to determine theoretically whether this breath-holding will produce levels closer to the asymptote than are found with normal exhalation in the standard breath test. On general grounds, however, knowing the average length of time for standard expiration into the Breathalyzer to be 22.8 seconds for the present sample, a breath-holding of 20 seconds plus half the standard expiration time should yield higher levels than the normal levels, although not by very much. It all depends on how close the normal breath is to the asymptote. One can predict, however, that the long breath should gain less from breath-holding than the short breath.

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**B.H.F. is now at the Neurological and Sensory Disease Control Program, U.S. Public Health Service, Arlington, Virginia; A.P. is at the School of Medicine, University of Copenhagen.
In regard to variability, it is hypothesized that the least variable of all should be the breath-holding plus half-time expiration, since this mode is assumed to approach the asymptote most closely, and since the asymptote should be least variable. The most variable is expected to be half-time expiration, and normal expiration time should have intermediate variability. If we designate normal expiration as Condition I, expiration with half the normal time as Condition II, and breath-holding with expiration time half that of a normal breath as Condition III, I and II are expected to be more variable than III.

Because the alcohol decline regression lines for the three conditions in any given subject are all supposed to reach zero alcohol at the same time, it was felt that this hypothesis should be tested. If they did not coincide, then some other factor would have to be working in this situation that must be taken account of.

One last item was observed, although only hypotheses can be conceived at this time. There are too few data here to yield data with confidence, but the observation was made anyhow. If there is no relationship, then any weight has the same distribution of rates as any other, and indeed, as the population. The correlation of a crude body build measure against normal breath metabolic decline rate was derived. The body build measure was the ratio of the cube root of weight, and height, that is, \( \left( \frac{\text{wt.}}{\text{ht.}} \right)^{1/3} \). Although excess fat should yield higher alcohol levels for equivalent intake, it should not affect rate if the correlation is truly zero.

**Procedure**

As in the previous study (1) subjects came in about 9 or 9:30 a.m. after having eaten a moderately light breakfast. Drinking began around 10 and breath tests were normally started 1/2 to 3/4 of an hour after the beginning of drinking. Among the 49 subjects tested some could not complete the testing because they became sick and had to leave. Others could only be given a small number of breath tests with the experimental types of breath deliveries and thus did not provide more than three breath deliveries under the second and third experimental conditions. A total of 39 subjects was left who satisfied all of the conditions necessary for this analysis. Three of these were more than 30 years of age. All the rest were college and medical school students. A minimum of one hour was allowed to pass before the first breath-reading contributing to the trend line of alcohol level decline was selected, and 1-1/4 hours where five drinks or more were taken. Normally this was the first or second breath-reading following the maximum. Occasionally, however, it was the highest alcohol level reached, and once in a while, the maximum followed it.

The maximum breath-reading in each of these series of points contributing to a regression line was recorded. The average maximum was 120.3 mg percent, with a standard deviation of 28.1 mg percent. Most of the sets of readings of alcohol decline ended in the region of 40 or 30 mg percent, thus permitting a prediction of the time of 0 percent in any curve of decline with only small error anticipated.

In Condition I the subject inhaled in anticipation of blowing. This was usually considerably more than tidal volume but probably did not quite reach full inspiratory reserve volume. To find the stability of blowing time, breaths through a mouthpiece were taken (time same as through the Breathalyzer) ten times per subject. Mean blowing duration (recorded to the nearest second) was 22.8 seconds, with a standard deviation, for 39 non-duplicating cases, of 8.08 seconds. The standard deviation of the 10 breaths was determined for each subject. These were averaged over the 39 subjects, with mean S.D. of 4.09 seconds and an S.D. range from .93 seconds to 9.97 seconds.

For each person the expiration time in Condition II was determined as the closest integral number of seconds to half of the observed full expiration time for Condition I. The subject inhaled as in Condition I, and exhaled for the specified number of seconds. The valve was turned at the end of the given number of seconds and the subject was told to stop blowing as soon as he saw the valve stop turning. The valve turned, of course, automatically cut off the breath entering the Breathalyzer.

In Condition III the subject was told to take a similar inhalation but to hold his breath for 20 seconds, after which he was told to blow through the mouthpiece into the Breathalyzer for the required time--the same length of time as Condition II. All subjects were able to do this.

The order of breath conditions was as follows, once the experimental Conditions II and III were begun: 1,111,1,11,1,111... Conditions III and II normally did not
begun until a few Condition I tests had been made, since the main experiment asked questions about phenomena associated with normal exhalation techniques. Thus, occasionally only a few breaths were available under Conditions II and III. Under Condition I, 49 regressions were derived with an average of 13.7 breaths (standard deviation = 4.00) contributing to each regression line of alcohol decline. For some people, determinations of Conditions II and III either were not available or the number of breaths was three or less. In such cases no slope was established for the regression line, since the error associated with three or two points was considered to be too great. All slopes derived from more than three observations were used. In Condition II the average number of breaths was 5.8, with a standard deviation of 2.78. In Condition III the average number of breaths for each regression was 6.2, with a standard deviation of 2.87. It was possible to determine regression lines under all three conditions in 39 sessions, with associated slopes and intercepts.

Results and Discussion

The rationale for the first set of hypotheses led to the prediction that the average slopes of the pencils of regression lines associated with each of the three conditions should have the following relationship:

1. \( b_{III} > b_I > b_{II} \)

The following values were actually found: \( b_{III} = 18.67 \text{ mg }/\text{hr} \); \( b_I = 18.24 \text{ mg }/\text{hr} \); and \( b_{II} = 17.47 \text{ mg }/\text{hr} \). The respective t-tests for differences between mean slopes associated with the different conditions were as follows:

- \( t_{I-III} = -1.05, p > .10, df = 38 \)
- \( t_{I-II} = 2.22, p < .05, df = 38 \)
- \( t_{II-III} = -2.72, p < .01, df = 38 \)

All t's were calculated on the basis of matched pairs. The data show the predicted relationship. However, it should be noted that in spite of the obtained excess of mean slope of Condition III over Condition I, that excess was not significant at the 5 percent level using a two-tailed test. One is not in a position, under the assumptions of such a test, to have confidence in the obtained difference, nor even to be quite sure that the sign of the difference was correct. On the other hand, a prediction was made in advance of the determination, which allows a one-tailed test to be used, according to some authorities. In this case, \( p < .05 \) for \( t_{I-III} \), and one has some confidence in rejecting the null hypothesis and making decisions based on such failure to reject. Whichever assumption is used, it is perhaps comforting to have observed that the smallest difference, as predicted, actually was found for I and III. One might say that this small difference is evidence that the normal expiration time allows inspired air in Condition I enough time to be very close to the asymptotic saturation that is felt to be desirable for a good determination.

The second hypothesis deals with the relationship among the variabilities of breaths associated with the different regression lines describing alcohol decline. The variability of breath around any given regression line is measured by the standard error of estimate of that regression line. The standard errors of estimate were determined for all the calculated regression lines and comparison made among the mean standard errors of estimate for the three different conditions. If we designate the unbiased estimate of the population standard error of estimate of a regression line as \( \sigma_{y,x} \), the following relationship among the mean standard errors of estimate of the three pencils of regression lines should hold:

2. \( \sigma_{y,x}^{III} > \sigma_{y,x}^{II} > \sigma_{y,x}^{I} \)

The results showed \( \sigma_{y,x} = 3.96 \text{ mg }%; \sigma_{y,x}^{II} = 3.27 \text{ mg }%; \) and \( \sigma_{y,x}^{III} = 3.42 \text{ mg }% \).

The respective t-tests between the mean standard errors of estimate showed:

- \( t_{I-II} = 2.03, p = .05, \text{ two-tailed, } df = 38 \)
- \( t_{I-III} = 2.43, p < .05, \text{ two-tailed, } df = 38 \)
- \( t_{II-III} = -3.5, p > .60, \text{ two-tailed, } df = 38 \)

Again, as above, using either one- or two-tailed tests, only that hypothesis was verified that predicted the variability of Condition III to be smaller than that of Condition I. It turned out, however, that the variability of Condition II was also

II. 49
less than that of Condition I. There appeared to be no difference between the variabilities of Conditions II and III. Obviously the hypothesis that Condition II should have a large variability was not borne out. It came from a decision regarding two possible effects on variability. The estimate of half-breath time was subject to half the error (departure from time to exhaust expiratory reserve volume) of full-breath time. It was felt that a half breath, with theoretic variability less than the variability of a full breath by a factor of only $\sqrt{2}$ (all other things equal), would still have larger variability than the full breath due to the theoretically closer approach of the full breath to the asymptotic temperature and vapor concentration equilibrium. It was felt that these factors—namely, the variation in degree of unsaturation and the difference in lung air temperature within the same subject on various occasions—would overbear the reduced variability associated with the direct time factor for blowing. In general, the standard deviation for a smaller expiration time would be expected to have variability proportional to the square root of the ratio of the two expiration times.

A second factor enters the picture. In the earlier work done on the question of accuracy of the Breathalyzer (1) it was shown that variability at low levels of alcohol was smaller than that at high levels of alcohol. This factor was operating in the present case, but the difference in alcohol levels between the two conditions at any given time (see below) was so small that that effect was not expected to have very much of an impact. On the basis of the results one is forced to the inference that for breaths on the order of 11 seconds, which was approximately the average half-breath time, the departure from the asymptotic state was not large enough to increase the variability to any major degree and therefore the factor of reduced variability stemming from the mere halving of the expiration time was prepotent in this situation and led to significantly reduced variability. A tentative conclusion from this fact is that the half breath in this sample, with average expiration time of about 11 seconds, is slightly more consistent than the normal breath, but also (see equation 1) understates the alcohol level. So far as breath-holding variability is concerned, that of Condition III did not differ, either with a one-tailed or a two-tailed test, from the half-breath variability of Condition II and would thus be preferred, following the results of equation 1. In view of the fact that the alcohol level found under Condition III exceeded that under Condition I by only a small amount, and its variability was significantly smaller than that of Condition I, the procedure for Condition III is to be preferred to that of Condition I, if it is possible to induce the subject to hold his breath for the required 20 seconds and exhale for the required short period of time.

The third hypothesis was that all three regression lines for each subject should indicate the disappearance of breath alcohol at the same time. The average $X$-axis intercept of all subjects for each condition should therefore equal that for each other condition, as follows:

$$X_{Y=0} = X_{Y=0} = X_{Y=0},$$

where $X$ is time and $Y$ is breath alcohol level. The mean $X$-axis intercepts for the three conditions were: $X_{Y=0_I} = 10.38$ hrs.; $X_{Y=0_{II}} = 10.43$ hrs.; and $X_{Y=0_{III}} = 10.46$ hrs. The respective tests of mean difference, again using matched pairs, were as follows:

- $t_{I-II} = -.49, p > .6, df = 38$
- $t_{I-III} = -.95, p > .3, df = 38$
- $t_{II-III} = -.30, p > .7, df = 38$

A null hypothesis such as we hold here, of course, requires a two-tailed test. The probabilities above reflect two-tailed values, as do the tabled $t$'s following equations 1 and 2. There is obviously no difference among the $X$-axis intercepts of the three conditions, permitting us to hold with greater confidence any conclusions based on that assumption. The greatest difference, that between the zero-alcohol times of Conditions I and III, amounted only to .08 hours, or five minutes.
The fourth hypothesis suggested that if a relationship between body build and metabolic rate existed it might be discovered here. The correlation between these two variables was .10, and therefore not significant. The hypothesis of no relationship cannot be rejected on the basis of these data.

It is of interest to set down the magnitude of differences between breath measures taken under the different conditions. Since the average X-axis intercept was the same for all conditions, it is possible to predict the breath levels for each at equivalent times, based on the average regressions, or alternatively, the values for each other condition, given a breath level in one condition. The latter approach will be used:

<table>
<thead>
<tr>
<th>Given Condition I, mg %</th>
<th>300</th>
<th>250</th>
<th>200</th>
<th>150</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted Condition II, mg %</td>
<td>287</td>
<td>239</td>
<td>191</td>
<td>144</td>
<td>96</td>
</tr>
<tr>
<td>Predicted Condition III, mg %</td>
<td>307</td>
<td>256</td>
<td>205</td>
<td>154</td>
<td>102</td>
</tr>
</tbody>
</table>

The differences are obviously not large. One can conclude that the conditions of the present experiment precluded major departure from almost full saturation, which appears to be the alcohol vapor state in Condition I. Therefore, since necessarily, zero exhalation time leads to zero alcohol level, the gradient of alcohol rise must be very steep during the first few seconds. Borkenstein (2) also reported a small difference from Condition I values with short breaths, ca. 7 seconds, in exploratory work on his new breath-storing device. The gradient, from the above, is therefore still relatively shallow at 7-11 seconds.

Major work still needs to be done. If breath is held (not too difficult with drunks, who often respond to challenge about personal capability), what duration of breath-holding will yield levels close enough to Condition I if expiration lasts only a few seconds? What is the gradient of breath level by seconds in the region 2-7 seconds? What effect does breath-holding of different lengths--and depths!!--have on this gradient?

Conclusions
1. In young people average exhalation time through a Breathalyzer is almost 23 seconds, using normal instructions for full exhalation.
2. Rate of decline of breath alcohol in young people, using exhalation time averaging 11 seconds, is about 4% smaller than their normal-test rate of decline, and 6% smaller than that obtained with 20 seconds of breath-holding preceding a similar exhalation time.
3. Consequently, the alcohol levels in this group with half-normal breath times will be about 96% of their levels with normal-breath times, and 94% of their breath-holding levels.
4. Breath-holding of 20 seconds with half-normal exhalation time increased breath alcohol levels in this group only about 2% over those with normal exhalation times, which may or may not be judged to obtain in the population at large, depending on theoretical position. We feel that it does obtain in the population.
5. Variability of breath alcohol levels with half-normal exhalation time is the same as that for breath-holding levels, but variabilities of both are less than that of levels found with normal exhalation time.
6. In young people, breath-holding is to be preferred over normal blowing procedure, in view of its lesser variability and comparable accuracy.
7. The technique of comparing pencils of regression lines under different conditions is acceptable provided that: their mean intercepts for zero alcohol are alike, and the number of regressions and number of cases per regression are large enough.
8. The data determined here do not contradict the hypothesis that body build is unrelated to rate of alcohol disappearance.

References