ISSN 1041-9489

SAFETY BRIEF

July 1993

Volume 8, No. 4

Triodyne Inc.
Consulting Engineers and Scientists
5950 West Touhy Avenue Niles, IL 60714-4610 (708) 677-4730
FAX: (708) 647-2047

MEDICAL SERIES

Under-the-Influence of Alcohol

by John P. Bederka, Jr., Ph. D.[1]

Introduction

To be, or not to be, intoxicated! The expert witness-consultant is frequently confronted with this question in litigation matters relative to alcohol in the human body under diverse circumstances. Even given a diverse range of circumstances, the basic information can be encompassed as follows:

- *Diving under the influence*
- *Driving under the influence*
- *Flying under the influence*
- *Skippering under the influence*
- *Walking under the influence*
- *Watching under the influence*
- *Working under the influence*

Herein, only a limited number of aspects of this diversity will be considered with deference to the experiences of the author. These selected topics will essentially span the complete alcohol experience with emphasis upon the following:

1. *The Egalitarian Nature of Alcoholic Beverages*
2. *Beverage-Specific Blood-Alcohol Concentrations (BAC's)*
3. *The Food Effect*
4. *Breath-Alcohol Analysis as Everyone's Size 8 Shoe*
5. *Breath-, Urine-, Vitreous- Blood Alcohol; Ratios, Ratios, Ratios!*
6. *Trauma and The Elimination Phase (Back Calculation)*
7. *"Frank Intoxication" or DUI as a Toxic Torque*
8. *How Many Drinks Did You Have? (More Back Calculations?)*
9. *Psychomotor Correlates of BAC's*
10. *Threshold Effects of Alcohol?*

[1] Senior Consulting Toxicologist, Triodyne Environmental Engineering, Inc., 5950 W. Touhy Avenue, Niles, IL 60714; (708) 647-6748.

A DRINK, ALCOHOL DOSAGE FORM OR WHAT'S IN A NAME?

Booze, by any other name, is still ethyl alcohol (ethanol) in effect! Beer drinking is very much different than whiskey drinking from the alcohol absorption (absorptive phase) perspective. Wine drinking, on the other hand, seems essentially non-existent from a litigation perspective. Thus, as Frezza et al.[1] have reported, and as noted by Conn[2], the alcohol contents of "beers, wines and whiskeys" can easily vary by a factor of two, as tabulated below:

Table 1. Percentage of Alcohol Contents of Some Drinks

Beers	
Light	about 2-3%
Regular	3.2 and 3.9-4.1%
England	Average 4.5%
Europe	6 or more%
Wines	
Light	9-12%
Fortified	20%
Whiskeys	37-50%

In many forums, however, the alcohol contents of beer, wine and whiskey are accepted as follows:

Table 2. Rule-of-Thumb Weights of Alcohol per Ounce of Drink

Beer	1 gram
Wine	3 grams
Whiskey	11 grams

Thus, this further allows a drug-based or unit-dose approach to drinking. And, as shown in table 3, a *beer*, a *wine* and a *whiskey* will afford the user an amount of alcohol per drink that is equal within about a factor of two.

Table 3. Amount of Alcohol per Unit-dose ("A Drink")

Beer	6-12 grams
Wine	9-12 grams
Whiskey	10-15 grams

Beverage-Specific Blood Alcohol Concentrations (BAC's)

As shown in Table 3, in spite of this seeming egalitarian basis of "A Drink," there are some further inequalities in terms of the drinker. We essentially all know from observation that the volumes and compositions of alcoholic drinks vary. One physiological variable in the drinker is likely to be a range of gastric emptying times. In an attempt to level the playing field in alcohol ingestion studies, fasting subjects are commonly utilized. Two reports are herein discussed in this regard. One study deals with beer drinking and the other with whiskey. Of personal interest to this author is the seeming lack of situations of DUI (Driving under the influence) where the alcohol was wine-derived.

The beer study by Perl et al.[3] utilized three light beers of 2.6, 3.14 and 3.60% v/v (volume of alcohol/volume of beer) and is illustrated in Figure 1. The subjects ingested six 285 ml glasses of beer at equal intervals over one hour. The BAC's were likewise measured over a period of 150 minutes. Thus, 35.1g, 42.4g and 48.6g of alcohol were consumed by the same group

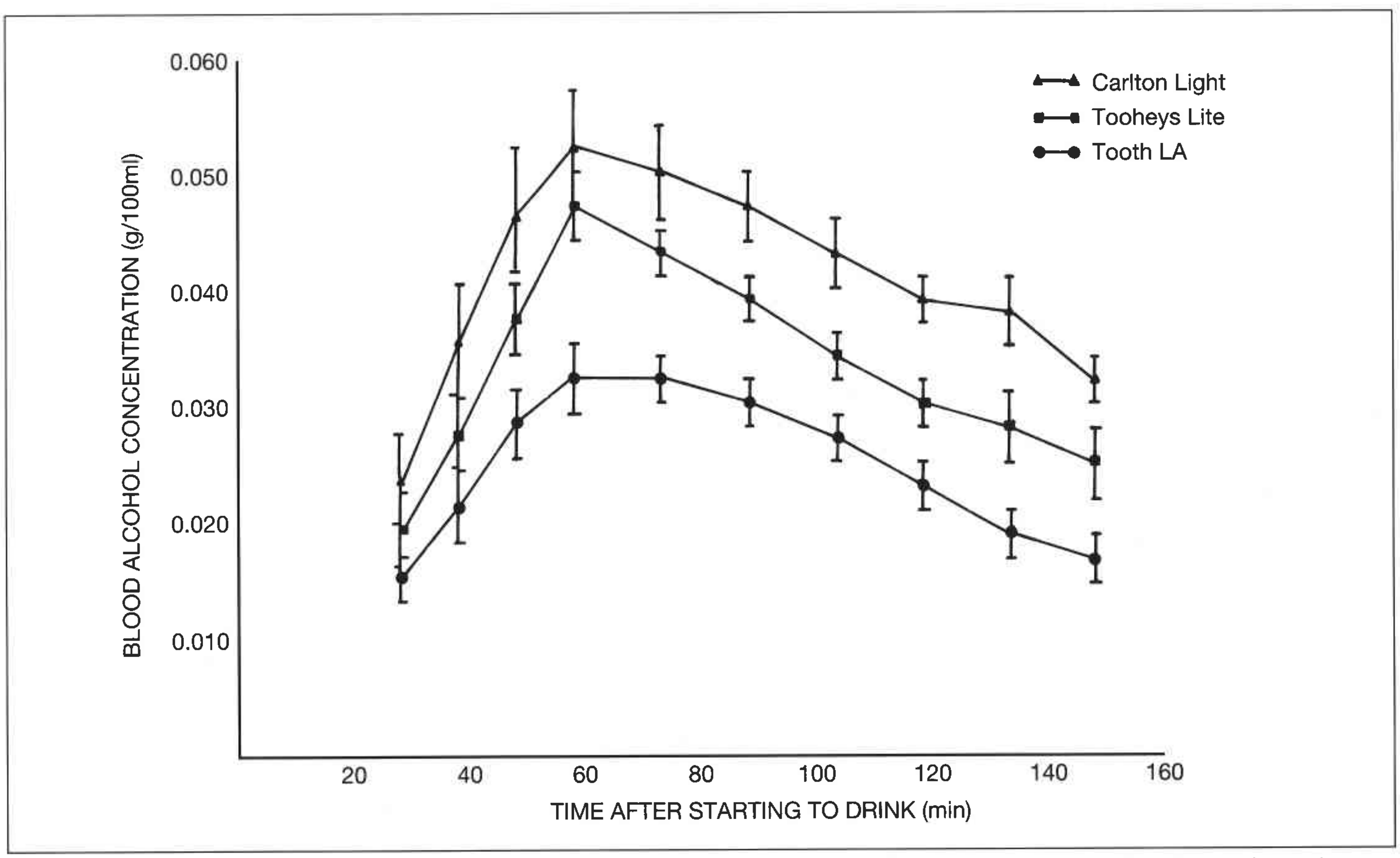

Figure 1. Mean blood alcohol concentrations (±SEM) in 10 males who consumed six 285-ml glasses of three "light" beers in one hour on three different occasions. (SEM is standard error of the mean).

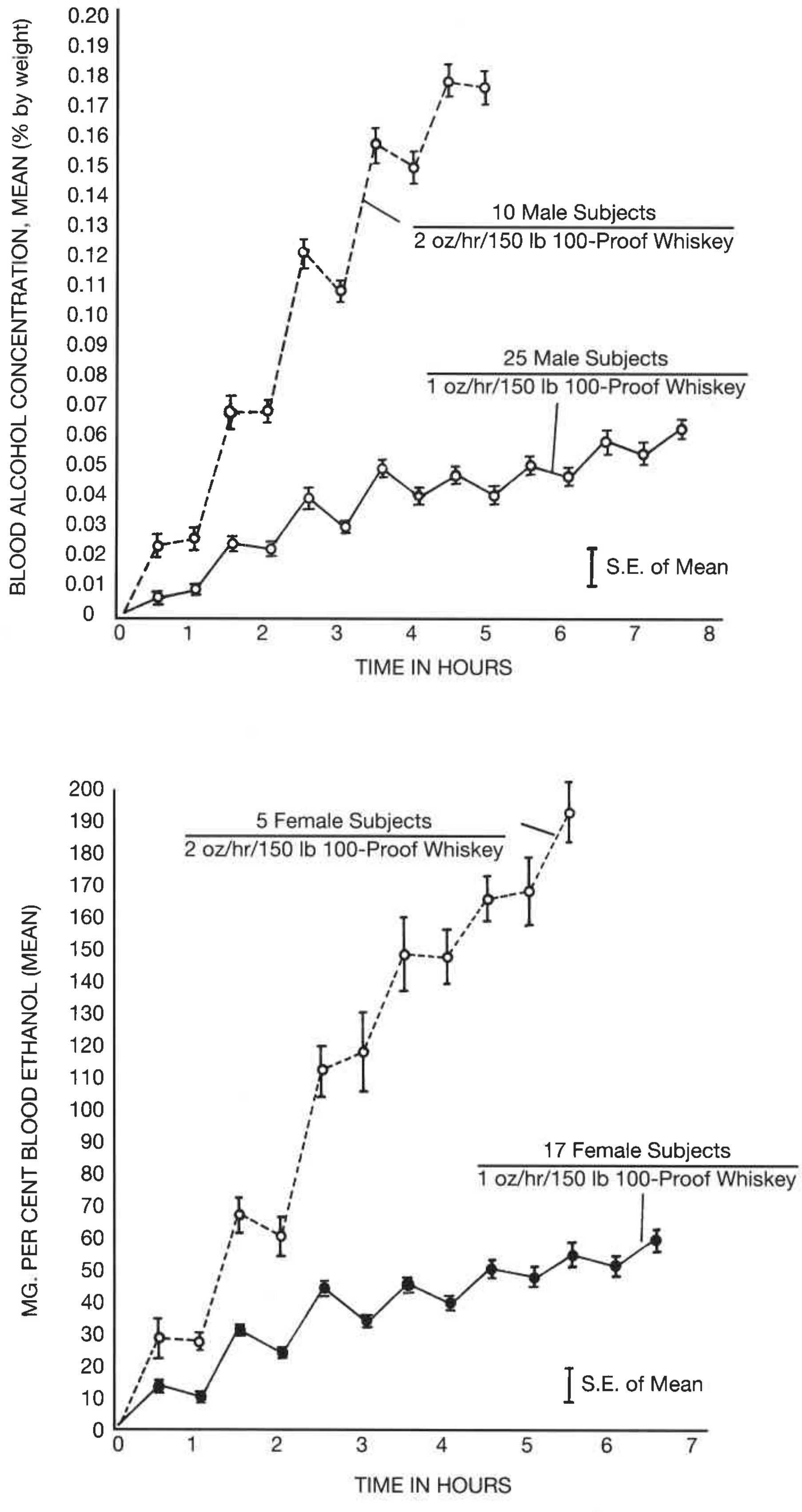

Figure 2. Mean blood alcohol concentrations in male and female subjects consuming 1 or 2 ounces of 100-proof whiskey/hour per 150 pounds of body weight. First drink at time 0 with one drink per each hour thereafter (after Forney and Hughes).

of ten men on three different occasions. The report clearly afforded plots of the average BAC's. Easily noted, therefore, were the ascending, plateau and elimination aspects of the blood-alcohol curves. They found peak BAC's at about sixty minutes after the beginning of drinking. Most importantly, the peak BAC's (plateau values) for the groups were about 30,45 and 52 mg% as a function of increasing alcohol contents of the imbibed products. Furthermore, at one hour post drinking, the BAC's were less than 50 mg%. The volumes of beers consumed were 1,710 ml/hr.

A similar study with whiskey drinking had been earlier reported by Forney and Hughes[4] with two groups of drinkers, as illustrated in Figure 2. One group consumed one ounce of 100-proof whiskey per hour. This is equal to about 12g of alcohol per hour. At one and a half hours (after two drinks), the average BAC was about 25 mg%, but in the group that consumed two ounces per hour, the BAC at 1.5 hrs into the drinking was about 65 mg%. [0.1% equals 100 milligrams (mg) % equals 100 mg/deciliter (dl)].

This value was thus achieved after consuming about 48 oz. of alcohol or four drinks of whiskey. The volumes of whiskey were equal to about one-tenth the volumes of beer noted in the above report. Moreover, with the further consumption of 2 ozs. per hour, a BAC of about 100 mg% was attained at about 2.5 hours of drinking. This is equal to six drinks or about 72g of alcohol in two hours. A further comparison shows that the consumption of about 48g of alcohol as beer in one hour would afford a BAC of about 40 mg% in two hours; while the consumption of 48g of alcohol as 100-proof whiskey in one hour affords a BAC of about 65 mg% in two hours. Thus, on a one or two drink per hour basis, the "Beer Drinker" would not attain a BAC above 60 mg% (0.060%) using these data by Perl et al. At a "shot" (one ounce of whiskey) per hour, the "whiskey drinker" would essentially never attain a BAC of 100 mg%. And, at two shots of 100-proof whiskey per hour, an average person would likely have a BAC above 100 mg% after about 2.5 hours of drinking.

The Food Effect: A Confounding Variable in the Alcohol-BAC Equation

The work by Goldberg[5] in Sweden in the late 1930s and early 1940s still seems as good as there is in regard to the effects of essentially concomitant eating and drinking. Thus, the consumption of certain foods an hour before or two hours after drinking may have little effect upon the profile of the Blood-Alcohol curve. This has not been studied, however, in terms of large ranges of volumes and types of foods and beverages. What has been reported and generally acknowledged is that food may shift the Blood-Alcohol Curve by at least a factor of two. Thus, food can cause a lowering of the maximum BAC by one-half and the time to peak BAC can be increased. For example, a peak BAC at 2-4 hours can be seen in studies with non-fasting drinkers. The effect of food seems to be greater with beer drinking. And, as reported by Goldberg,the BAC can be lowered by more than 50% in one drinking 80-proof brandy when food is also ingested. This magnitude and direction of food effect has also been found in several more recent studies as summarized in the text edited by Crow and Batt[6].

A Breathalyzer Test Result is Everyone's Size 8 Shoe

Once upon a time, there was a perceived urgent need to do something about the bad drinking driver. So, some very bright well-meaning persons developed a testing method that was user-friendly and could possibly lead to the extinction of drinking drivers. Post haste, you see, these well-meaning persons could effectively smell this need, and they went out into the laboratories (not the streets) and studied many bad drinking persons (not driving). First, they created a machine. Then, they measured and measured and measured the expired air for many years with many machines. Alas, it came to pass that drinking persons were found to have alcohol in their blood, as well as in the air that they forcefully breathed out. It was further found, after many attempts, that there was an average value in the population of drinkers that described the amount of alcohol detected in the blood, and the amount of alcohol detected in the breath. Thus was created the Blood-Breath Ratio (B-B/R). This Ratio was, in the beginning, created about equal to 2,100:1. In time, however, the new creators have made it equal to about 2,300:1, since it was found that most drivers were not still drinking while crashing. And it has come to pass that all men and all women are considered created equal with a ratio of one of the above, depending upon which machine is used. The view of this author is consistent with the statement of Mason and Dubowski regarding "the unacceptable lack of agreement of found and calculated concentrations in numerous blood-breath correlation studies. . .and in the discordant values reported for the blood-breath concentration ratio for alchohol. . ."[21]

Now, once upon another time, another group of wise persons in the leather-plastic business were also out to create for themselves an even playing field. So they also went out into the wilderness (city streets, etc.) and measured a large group of persons' foot sizes. And, lo and behold, they found that the population had an average foot size of about 8. These wise persons thus created machines with the right (equal) ratios and produced various size 8 shoes for all of us. What, not quite clearly a great analogy you say? But yet it seems that a breathalyzer test result is tantamount to everyone's size 8 shoe! Still don't like the comparison? Well, then let me try to clarify my dilemma further with this Ratio (B-B/R). The following tabulation (Table 4) is an expansion of the data in the paper by Moore[7]. He, and many others,[8,9,10,11] measured blood alcohol and breathalyzer- derived BAC's in select populations. Thus, they have tabulated and averaged the calculated BAC's based upon either the 2100 or 2300 Ratio and, with the actual BAC, as determined with an actual blood sample, noted the actual ratios for the individuals. The range of Ratios from about 850 to 7300 is the reality. The fantasy is that we all have the ratios fixed in the breathalyzers! The individual calamity is that with a breathalyzer-derived result of 83 mg%, one could have a BAC of anywhere from about 34 mg% to 285 mg% (about 8-fold). It is doubtful that these drinkers have such a range of shoe sizes!

Table 4. Alcohol in Blood, Breath and the Ratios Thereof for Selected Groups or Individuals

Blood (Actual value ±5%)	Breath	Ratio
0.034	0.083	850
0.068	0.083	1,725
0.083	0.083	2,100
0.089	0.083	2,280
0.156	0.083	4,000
0.285	0.083	7,300

Even given the inherent defect in breath-test results shown in Table 4, a positive breath test is not to be ignored! A positive breath test is an almost certain indicator of the presence of either an abnormal chemical component in the expired air or an abnormal amount of a frequently occurring body component. Thus, although the breathalyzer may have good precision, i.e., reproducibility of a test result, the accuracy in terms of true blood-alcohol level is highly questionable; and chemicals other than ethanol afford positive test results! **On balance, a breathalyzer is a very good screening tool for alcohol and alcohol-like respirable chemicals. Nothing more!**

Breath-, Urine-, Vitreous-Blood Alcohol; Ratios, Ratios, Ratios!

As presented in the foregoing, breath-alcohol testing is an attempt at indirectly ascertaining the amount of alcohol per unit of blood, thus the ratio of Blood-to-Breath alcohol. Could it be, however, that there may be a better indirect measure of the blood alcohol concentration (BAC)? How about Urine? Vitreous fluid of the eye? Saliva?

Urine-alcohol values under diverse conditions are widely reported in the literature.[12,13,14,15,16] In general, the relationship of Urine-to Blood-Alcohol and the mental leap to degree of intoxication is not an often performed feat in the judicial arena. However, a review of some recent ratio data in this regard seems in order. Thus, of 229 values for the urine-blood alcohol ratio (U-B/R), from four publications, the average range of ratios was 4.1, 4.8, 13.1, 14.1. These ratios compare with breath-based values of 1.6, 3.3, 6.6 & 8.7. The difference between the urine- and breath-based testing would be less than a factor of two. This situation suggests that the widespread use of the breathalyzer types is begging the issue! The question is how justifiable is the use of breath testing to damn; while damning urine-alcohol data? The validity of urine-alcohol and breath-alcohol values as measures of blood alcohol is arguably equally bad!

Given that saliva is remarkably available and variable in consistency by virtue of parasympathetic and possibly competing innervation and other factors, it is not surprising that a consistent test procedure based upon salivary alcohol is not yet available. On the contrary, vitreous fluid is not likely to become a more common test for alcohol, unless a non-invasive and non-postmortem method for sampling is developed. More to the point is the fact that the average ratios of vitreous to blood alcohol from 572 cases were remarkably low and consistent at 2.71, 3.58 and 3.95.[17,18,19,20] Of additional consideration is the fact that the eye is a direct part of the brain. Thus, it would seem of some interest to correlate vitreous alcohol and intoxication in addition to blood alcohol and intoxication.

In summary, then, it is glaringly clear that there is great individual variability relative to all of the above ratio-based attempts at indirectly gauging the blood- alcohol concentration. Really, how can one even begin to assume that an average value of the Blood-Breath Alcohol Ratio applies to the individual. One must reasonably conclude that all of the available indirect tests toward blood-alcohol values are screening procedures at best! It is tantamount to criminality to use a breath-alcohol test result as a true measure of the Blood-Alcohol Concentration. Thus, it is truly inconceivable to read that breath-alcohol values alone are being touted as a legal venue in alcohol-related matters.[21] The only reasonably reliable and the best approximation of the Blood-Alcohol Concentration is a blood-alcohol determination!

Trauma and the Elimination Phase: Back Calculation-Extrapolation-Interpolation-Inspiration

What was the BAC at the time that. . . ? The answer to this question is the song that everyone waits for the Fat Expert Witness to Sing! The lyrics usually include:

Weight	*Sex*
Amount	*Type*
Times	*Food*
Absorption Phase	*Plateau Phase*
Elimination Phase	*Metabolism*
Intravenous Fluid	*Blood loss*
Site of Sampling	*Type of Instrumentation*
Quality Control	*Blood Chemistries*
Blood Count	*Sobriety Testing*
Drinking History	Et cetera

Usually, somewhere in the file records, there is a BAC or two. And as noted in the foregoing, the published scientific literature allows that a plateau BAC is reached within two hours of the termination of drinking. The absorption phase can, however, be as brief as thirty minutes; or, with food, as long as about four hours. Also, the BAC can remain at ±10% of a plateau value for about two hours. Additionally, the BAC can vary by ±10% with small blood-drawing intervals. And, finally, in the elimination phase of the Blood-Alcohol Curve, the published literature allows a range of rates of alcohol removal from the blood of between 10 and 30 mg/dl/hr. With the special case of the trauma victim, an alcohol loss in the upper portion of this range has been reported by Raszeja and Olszewska.[22] In fact, the highest rates that this author has encountered are in the 40-50 mg/dl/hr range in a hospital setting, which values are in agreement with those recently reported by Adachi et al.[23]

Ideally, for a back-calculation exercise, it is always more firm to have two BAC's at least two hours apart in the same clinical setting, as noted essentially by Fitzgerald and Hume.[24] In this author's experience, however, this two-BAC test situation obtains in less than 10% of alcohol-related matters. Thus, given one BAC, and considering clinical interventions, times from incident (accident) to blood draw, and certain pre-accident events as per the foregoing, a back-calculation of BAC's with time then becomes a matter of arithmetic. This process is directed by some to afford a single value for the BAC at the time that. . . ! However, in view of the many variables that usually enter into each matter, a range of BAC's is the reasonable product of a back calculation, as most recently noted in an attempted review by Montgomery and Reasor.[25]

DUI as a Toxic Torque or "Frank Intoxication"

Question to the expert: "What can you say about the Degree of Intoxication at the time that. . . ?"

As has been stressed in the foregoing, indirect methods of blood-alcohol estimation are at best screening tests. An analogy is available in the case of drug abuse testing where screening test results must be complemented by a confirmatory test result. This attempt to relate BAC and Intoxication therefore demands that a direct

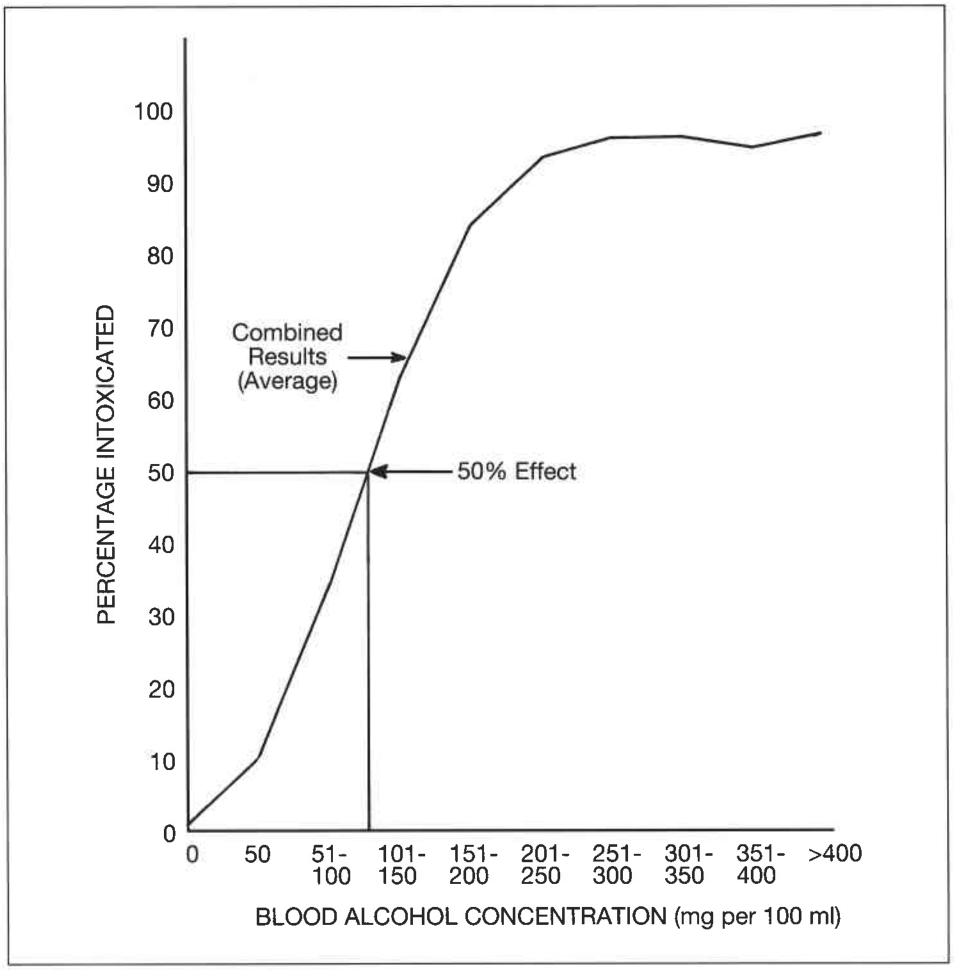

Figure 3. Relationship between blood-alcohol concentration and percentage of subjects intoxicated.

blood-alcohol value be obtained even at some inconvenience.

So, now that we have an acceptable blood alcohol result, are we at a DUI State of Nirvana? Shall I dare to say, not quite? If I cannot be more absolute with a direct blood alcohol result, then how can I possibly proceed from a breath alcohol posture to Degree of Intoxication? Well, it is generally the law!

In reality, the use of the term and concept "Frank Intoxication" seems to have served this writer quite well. As reported by Jetter,[26,27] and based upon 5,853 subjects, "Frank Intoxication" (FI) is a sign-based evaluation that requires a gross gait abnormality and any two of the following four:

1. abnormality of speech
2. dilated pupils
3. flushed face
4. odor of alcohol on the breath

The data in the report by Jetter allows that a BAC in the range of 101-150 mg/dl would have about 64% of the subjects considered as "Frankly Intoxicated." Moreover, in the group of persons at BAC's between 51 and 100 mg/dl, 34% were considered to be frankly intoxicated. These combined data, as illustrated in Figure 3, allow that about 50% of a population would be frankly intoxicated at a BAC of about 125 mg/dl; and 95% of an average population would appear to be FI at about 200 mg/dl or above.

How Many Drinks in a BAC? (More Back-Calculations?)

Before closing on this topic, there is one more frequently encountered issue that merits consideration and comment. It is appropriate that this evaluation occurs at this place in the article. The Issue is a question that is usually formulated as a variation of the general query, "How much did you have to drink?" The answer that is usually offered is "one-or-two!" And this scenario is usually focused upon a blood-alcohol value of about 0.125%.

Now at this point, either our "Expert" and/or our solicitor remembers that a table of numbers exists somewhere on this very topic (e.g.,[2,25,26,27]). Furthermore, the "Expert" remembers that a formula exists for the purpose of creating the table, if not for some other lofty purpose. Thus, by way of review, we can note some of the caveats inherent in any attempt to relate a blood-alcohol concentration to the number of "drinks" consumed. Referring to Table 1, it is seen that not all drinks are created equal. As noted, these "drinks" vary in alcohol content by a factor of about two. Moreover, the volume of the "drink" may vary by more than a tenfold factor, to say nothing about the volume of the "drinker." It seems, therefore, that a statement as to the number of "drinks" should carry at least a twofold estimation error. One could further see that some "drinks" may be double shots of some generosity; and, occasionally, one may also assume some penurious efforts at drink preparation. Thus, at this stage, it would seem appropriate to use an estimation error factor of two- to four-fold in drink estimation, even at relatively low BAC's for the estimator.

More critical, however, is the variability in the estimation of the number of "drinks" when the estimator is the non-biased "Expert." Given that the beginning assumption of the equivalency of "drinks" as to alcohol content is incorrect, one still finds that this assumption is used in theory and practice.[25] In fact, as noted above, and as is generally found in the literature, the elimination phase of the BAC is dosage-form independent. Thus, even though the alcohol in the blood is not identifiable as to either beer-, wine- or whiskey-derived, there is at least a two-fold to four-fold variation in the rate of alcohol loss from the blood. So, against all logic, how could the absorption phase be less variable than the elimination phase? Referring to Figures 1 and 2, one can note that the absorption phase is dosage-form dependent; that is, the same number of "drinks" does not afford the same BAC's!

The critical factor that is generally lost to these number of drinks-BAC calculations is Time. Thus, Time during which drinking occurred and Time since drinking ceased are also primary variables.

Let us further examine here what I will call a very limiting case, as shown in Figure 2.

Note that at a BAC of about 0.02-0.025%, one has consumed either a double shot (two ounces) or two single shots (two one-ounce doses). One could rightly calculate that two "drinks" gave the same BAC. Moving right along the curves, we note that at four "drinks" (two two-ounce shots), one has a BAC of about 0.065% and at four "drinks," (four one-ounce *shots*), one has a BAC of about 0.04%. Whoops! Well, let us keep moving right along to six "drinks." Now at three two-ounce "drinks," we have a BAC of about 0.11%, and also at six "drinks," (six one-ounce shots), we note a BAC of about 0.04%. So, even with a limiting case scenario of BAC predictabiity and number of "drinks," one can note an estimation error factor of up to three-fold or more.

In summary, it seems quite obvious that an attempt to back calculate the number of "drinks" relative to a given BAC is less than either precise or accurate. Included in the reality of the matter are at least the following:

- Rate of drinking
- Time of, and time since, drinking
- Ethanol elimination rate less than a five-fold factor
- The food effect of up to a four-fold factor[5,24]
- Variable absorption phase factors[28]

It is quite obviously the conclusion of this writer that an attempt to back calculate the number of "drinks" consumed or the equivalent relative to a given BAC is a most futile and inaccurate task and any number derived therefrom has little to no general validity.

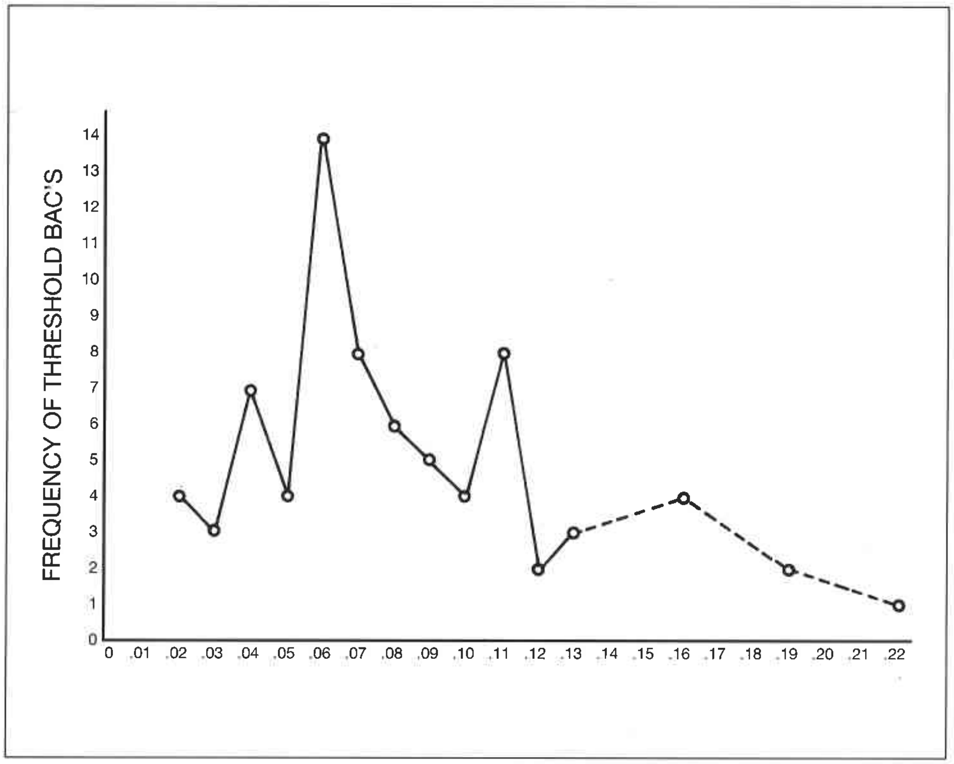

Figure 4. Reported BAC's at Thresholds for Significant Hypofunctionality (% Alcohol per 100 ml of Blood or Blood approximation via Breath).

Psychomotor Correlates of BAC's

The experience of the author has been that most alcohol-related matters focus at BAC's around the 100 mg/dl (0.100%) level and above. In the other direction, what is the lower limit of BAC where test parameters fail to be predictive of the degree of psychomotor hypofunctionality? Or, when can you significantly talk of a no-effect level of alcohol? A recent review of the data presented in the text edited by Crow and Batt[6] has allowed the construction of the following two figures which data are based upon about eighty published articles. Figure 4 shows a plot of the frequency distribution of threshold BAC's for effects upon diverse human factors parameters. Figure 5 is a plot similar to Figure 3 of cumulative frequency distribution of lowest BAC's at hypofunctionality.

In both figures, a major inflection point is noted at BAC's of about 0.06-0.07% (60-70 mg/dl). This value of about 0.070% is also quite consistent in terms of a limiting BAC for alcohol-facilitated psychomotor performance which is usually noted below about 0.05% BAC. In somewhat Pharmacologic/Toxicologic terms, Figure 5 is a dose-response curve. Consequently, a value of the BAC that affects 50% of the variables can be derived. This 50% effect is the above-noted BAC of 0.070%. This 50% effect in the laboratory-based test situation is about one-half the field-test derived 50% "Frank Intoxication" BAC of 0.125% noted above. In the other direction, one would have a seeming 95% probability of exhibiting no psychomotor hypofunctionality at a BAC of about 20 mg/dl.

Threshold Effects of Alcohol

As noted in the foregoing, both academic and practical goals were being pursued by researchers in the arena of psychomotor effects of ethanol. The utility of this research information for the expert witness is usually such that the effects of alcohol can be described as a probabilistic event in terms of the inebriated. For example, one can address the question as to whether there was a greater than 50% likelihood of intoxication or even one greater than 95% in the case of a high BAC. The reverse situation, however, usually obtains! Thus, what was the likelihood of being functionally normal at a BAC below any of the litigated values of 0.1%, 0.05%, etc. Here one would not be driving under the influence, but one could still be under the influence.

Referring to the data of Figures 4 and 5, one notes about 80 data points. In effect, each of these data points likely has devolved from some study on some human factor parameter. The question that needs to be considered is: "which parameter or parameters are appropriate to the alcohol-related incident under consideration?" Posing an approach to an answer to this possible question are the items in Table 5. These six areas of psychomotor functioning could be related to the driver and/or passenger, and perhaps to the eye witness.[29] Especially to be noted relative to the alcohol concentrations in Table 5 is the fact that these concentrations refer to the extinction-initiation of hypofunctionality; that is, the alcohol concentrations could be considered as threshold values for the effects of the alcohol.

One final interpretation from the data in Figure 5 is that there is some human factor parameter that is affected in some persons at blood-alcohol levels that are in the area of 0.01% (10mg/deciliter). Furthermore, with additional work and with more sophisticated instrumentation, it will be concluded by someone that there is no lower limit for the effect of alcohol except zero.

In closing on this topic of the influence of Alcohol on Human Performance, the word *alcohol* does not generally cause intense intellectual interest. The real world incidents involving alcohol, however, are all unique. The variables noted in the foregoing are by no means an exhaustive listing; and, no attempt was made to treat any topic exhaustively. All in all, there is enough supporting scientific and related literature to be objective about alcohol-related matters. There are data from population studies that afford average values and ranges of values. Additionally, there are data on individuals over time which allow more specific approximations. Thus, one must carefully excerpt the literature and focus one's experience-cum expertise in evaluating the alcohol-human interactions. Especially illustrative in this regard are the numerous studies of psychomotor performance of humans under the influences of alcohol noted, in regard to Figures 4 and 5. To select the appropriate test data from this universe of information and objectively to address matters involving alcohol, is clearly no small responsibility for the expert witness.

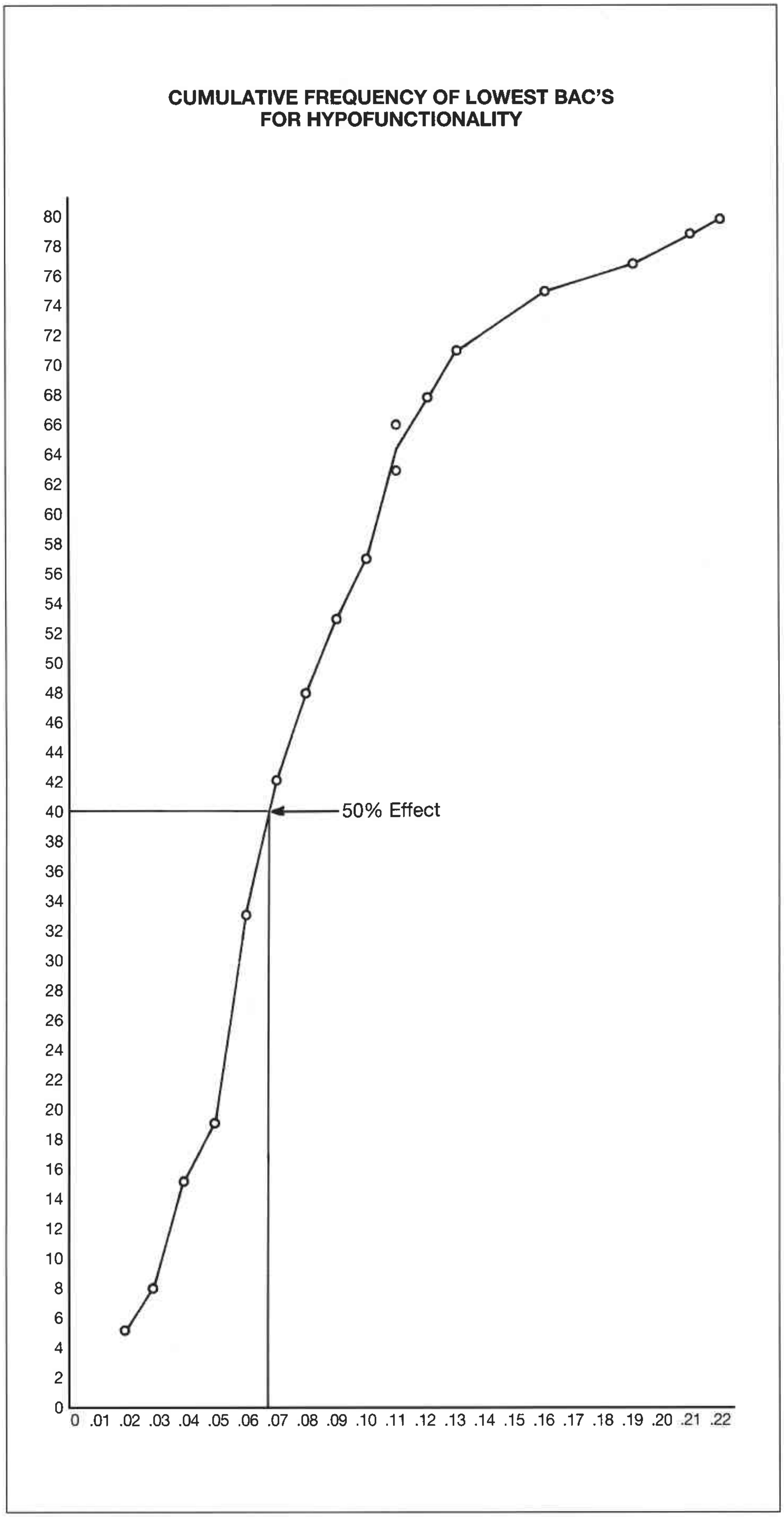

Figure 5. BAC's at Thresholds for Significant Hypofunctionality

SIGN OR SYMPTOM	APPROX. BLOOD ALCOHOL
Alcohol and Perception	
Dynamic Visual Acuity	ca. 0.02%
Light-Dark Adaptation	0.09%
Peripheral Vision (Multi-Tasking)	0.05%
tasking of great difficulty	0.017%
above 0.08% peripheral events ignored	
Eye Blink Frequency and Blink Closure	0.07%
Color Discrimination	very variable
Oculomotor Function	
Depth Perception	0.015-0.04%
Sacchadic Eye Movements	0.05-0.10%
Nystagmus of Various Types	0.03 - 0.09%
Tracking Tasks	
With Angular Acceleration	0.07%
added multi-tasking	0.03-0.06%
about 90% of subjects affected at	0.10%
Division of Attention	
Vigilance (Multi-Tasking)	0.015%
Fixation Time (Foveal Focusing)	0.10%
Mood and Emotions	
Increased Drowsiness and Decreased Clear Headedness	0.03%
Memory	
Short-Term Input and/or Recall Spans	0.05-0.10%

Table 5. Some alchohol-sensitive psychomotor functions and approximate threshold alchohol concentrations

REFERENCES

1. Frezza, J. et al., "High Blood Alcohol Levels in Women," *New England Journal of Medicine* v.322 (1990): 95-99.
2. Conn, H.O., "Alcohol Content of Various Beverages: All Booze is Created Equal," *Hepatology* v.12 (1990): 1252-1254.
3. Perl, J., G.A. Starmer and K.D. Bird, "Blood Alcohol Concentrations after 3 "Light" Beers," *The Medical Journal of Australia* v.1 #13 (June 25, 1983): 599.
4. Forney, R.B. and F.W. Hughes, "Alcohol Accumulation in Humans after Prolonged Drinking," *Clinical Pharmacology and Therapeutics* v.4 (1963): 619 - 621.
5. Goldberg, L., "Qualitative Studies on Alcohol Tolerance in Man," *Acta Physiologica Scandinavica* v.5 Suppl. XVI (1943): 1-128.
6. Crow, K.E. and R.D. Batt, eds. *Human Metabolism of Alcohol* vol. 1. Boca Raton, FL, CRC Press, 1989.
7. Moore, R., "Concerning Breath Alcohol Measurements during Absorption and Elimination," *Journal of Analytical Toxicology* v.15 (1991): 346-7.
8. Jones, A.W., "Variability of the Blood:Breath Alcohol Ratio in vivo," *Journal of Studies on Alchohol* v.39 (1978): 1931-1939.
9. Dubowski, K.W. and B. O'Neill, "The Blood/Breath Ratio of Ethanol," *Clinical Chemistry* v.25 (1979): 1144.
10. Simpson, G., "Reply to 'Incorrect Reanalysis of Breath/Blood Alcohol Data,' " *Journal of Analytical Toxicology* v. 15 (1991): 220-222.
11. Gullberg, R.G., "Statistical Evaluation and Reporting of Blood Alcohol/Breath Alcohol Ratio Distribution Data," *Journal of Analytical Toxicology* v.15 (1991): 343-44.
12. Jones, A.W., "Ethanol Distribution Ratios between Urine and Capillary Blood in Controlled Experiments and in Apprehended Drinking Drivers," *Journal of Forensic Sciences* v.37 (1992): 21-34.
13. Backer, R.C., R.V. Pisano and I.M. Sapher, "The Comparison of Alcohol Concentrations in Postmortem Fluids and Tissues," *Journal of Forensic Sciences* v.25 (1980): 327-331.
14. Heatley, M.K. and J. Crane, "The Relationship between Blood and Urine Alcohol Concentrations at Autopsy," *Medicine, Science and the Law* v.29 (1989): 209-217.
15. Budd, R.D., "Ethanol Levels in Postmortem Body Fluids," *Journal of Chromatography* v. 252 (1982): 315-318.
16. Caplan, Y.H. and B. Levine, "The Analysis of Ethanol in Serum, Blood, and Urine: A Comparison of the TDx REA Ethanol Assay and Gas Chromatography," *Journal of Analytical Toxicology* v.10 (1986): 49-52.
17. Felby, S. and J. Olsen, "Comparative Studies of Postmortem Ethyl Alcohol in Vitreous Humor, Blood, and Muscle," *Journal of Forensic Sciences* v.14 (1969): 93-101.
18. Leahy, M.S., E.R. Faber and T.R. Meadows, "Quantitation of Ethyl Alcohol in the Postmortem Vitreous Humor," *Journal of Forensic Sciences* v.13 (1968): 498-502.
19. Sturner, W.Q. and J.C. Garriott, "Comparative Toxicology in Vitreous Humor and Blood," *Forensic Science* v. 6 (1975): 31-39.
20. Caplan, Y.H. and B. Levine, "Vitreous Humor in the Evaluation of Postmortem Blood Ethanol Concentrations," *Journal of Analytical Toxicology* v.14 (1990): 305-307.
21. Mason, M.F. and K.M. Dubowski in *Medico-Legal Aspects of Alcohol Determinations in Biological Specimens*, J.C. Garriott, ed. Littleton, MA, PSG Publications, 1988, pp. 101-110. (Quoted by G. Simpson, "Medicolegal Alcohol Determination: Comparison and Consequences of Breath and Blood Analysis," *Journal of Analytical Toxicology* v.13 (1989): 361-366).
22. Raszeja, S. and I. Olszewska, "Der Einfluss des Traumatischen Schock auf die Geschwindigkeit der Alkoholelimination," *Zietschrift fur Rechtsmedicin* v.86 (1981): 277-280.

23. Adachi, J., K. Kuriyama, A. Takada and H. Ishii, "Ethanol Elimination Rate and Blood Acetaldehyde Level in Alcoholics," in *Biomedical and Social Aspects of Alcohol and Alcoholism.* Amsterdam, Elsevier Science Publishers, B.V. Biomedical Division, 1988, pp. 107-110.

24. Fitzgerald, E.F. and D.N. Hume, "The Single Chemical Test for Intoxication: A Challenge to Admissibility," *Massachusetts Law Review* (Winter 1981): 23-37.

25. Montgomery, M.R. and M.J. Reasor, "Retrograde Extrapolation of Blood Alcohol Data: An Applied Approach," *Journal of Toxicology and Environmental Health* v.36 (1992): 281-292.

26. Jetter, W.W., "Studies in Alcohol. I. The Diagnosis of Acute Alcoholic Intoxication by a Correlation of Clinical and Chemical Findings," *American Journal of Medical Science* v.196 (1938): 475-487.

27. Jetter, W.W., "Studies in Alcohol. II. Experimental Feeding of Alcohol to Non-Alcoholic Individuals," *American Journal of Medical Science* v.196 (1938): 487-493.

28. Gordon, I., H.A. Shapiro and S.D. Berson, "Medico-Legal Aspects of Acute Alcohol Intoxication," in *Forensic Medicine*, 3rd ed., New York, Churchill-Livingstone, 1988, pp. 396-435.

29. Fruzzetti, Alan E., Kelly Toland, Stephen A. Teller and Elizabeth F. Loftus, "Memory and Eye Witness Testimony," Chapter 2 in *Aspects of Memory*, vol. 1, M. Gruneberg and P. Morris, eds. London, Routledge, 1992, pp. 18-50.

ABOUT THE AUTHOR

John P. Bederka received his Bachelor of Science in Chemistry in 1959 and his M.S. in Organic Chemistry from West Virginia University in Morgantown in 1961. He completed a year of post-graduate study at Washington State University in Pullman. He then conducted his doctoral research on the study of radioactively labeled derivatives of nicotine and the nicotinamides, which lead to his Ph.D. from the Medical College of Virginia at Richmond in 1967. Dr. Bederka was awarded a postdoctoral Fellowship at the University of Minnesota where he specialized in neuropharmacology and the physiological distribution of drugs.

At the invitation of the Rockefeller Foundation, he joined the faculty of Mahidol University in Bangkok, where he played a key role in developing a new graduate studies program in the University of Medical Sciences, while teaching pharmacology and toxicology courses. Upon his return to the U.S. in 1971, Dr. Bederka joined the faculty of the University of Illinois at the Medical Center in Chicago, where he reorganized the pharmacology curriculum with an emphasis on toxicology. In 1977, he assumed responsibilities as Head of the Toxicology and Pharmacometrics section of the Hospital Laboratories in the Department of Pathology at the Abraham Lincoln School of Medicine in the Medical Center in Chicago. Dr. Bederka left the University of Illinois in 1983 to join a commercial clinical laboratory, Doctor's Data, Inc. in West Chicago, as Vice President of Research,with a focus on Toxicology and Atomic and Molecular Nutriture. In 1988, Dr. Bederka established a private forensic services consulting practice and joined Triodyne Environmental Engineers as Senior Consulting Toxicologist.

Dr. Bederka has published extensively in the medical literature and co-edited the textbook, *Survival in Toxic Environments*, published in 1974 by Academic Press. Dr. Bederka specializes in forensic toxicology services covering a broad spectrum of personal injury matters, including substance abuse, childhood plumbism, fire deaths and exposures to carbon monoxide, hydrogen cyanide, dioxins, PCBs, various insecticides and herbicides, organic solvents and toxic metals, among a host of other substances.

What is a Defect?

The definition of a defective product in a state may be found in the case law of that state. In our Safety Briefs, we explore leading product liability case law for one or more states. Triodyne Inc. relies on the trial bar for selection of the cases cited.

NEW HAMPSHIRE

New Hampshire recognizes two types of defective products: one which is defective in its design and one which contains a manufacturing defect.

> "A design defect occurs when the product is manufactured in conformity with the intended design but the design itself poses unreasonable dangers to the consumers."
>
> A manufacturing defect is "an accidental variation caused by a mistake in the manufacturing process; that is, that the product does not 'conform to the great majority of products manufactured in accordance with that design.'"

The case of *David W. Thibeault v. Sears Roebuck and Company*, 118 N.H. 802,395 A.2d 843(1978), presented one of alleged defective design; no manufacturing defect was claimed.

David W. Thibeault sustained a foot injury while using a *Craftsman* rotary power mower which he purchased from Sears Roebuck and Company in 1968. The lawn mower housing was embossed with a warning "keep hands and feet from under mower" and the owner's booklet cautioned the operator to mow slopes lengthwise, not up and down. Despite this advise, while mowing a long steep slope on his property in an up and down fashion, the plaintiff lost his balance, fell, and his foot went under the mower.

The plaintiff claimed the mower was defective since it lacked a rear trailing guard. In overruling the plaintiff's appeal from a defendant's verdict, the New Hampshire Supreme Court examined the state of strict liability law in the State of New Hampshire in a comprehensive way.

In order for strict liability to arise as a result of a defective design, the plaintiff must allege and prove that the defective condition was unreasonably dangerous to the user. In making this determination, the trier of fact should consider factors such as the product's social utility and desirability. In so doing, the Court should consider whether the risk of danger could have been reduced without significant impact on the product effectiveness and manufacturing cost. Accordingly, liability may attach if the manufacturer does not take available and reasonable steps to lessen or eliminate a danger of even a significantly useful or desirable product.

When a risk of injury is not apparent, a manufacturer must adequate ly and understandably warn the user of concealed dangers. Some products, however, are obviously and inherently dangerous, such as carving knives, and no warning is necessary. New Hampshire does not consider a product unreasonably dangerous if the risk of harm is extremely remote, nor is a manufacturer required to warn against uses neither intended nor reasonably foreseeable by the manufacturer. Consumers have responsibilities and manufacturers cannot foresee and warn of all absurd or dangerous uses of their product.

A manufacturer may not escape liability by claiming the risk of harm was obvious or that the user was adequately warned if an unreasonable danger could have been eliminated without excessive cost or loss of product efficiency. Nevertheless, a manufacturer is not obligated to design the safest possible product: The adopted design, however, must be reasonably safe.

A plaintiff in a defective design case must also prove causation and foreseeability. The defect must exist when the product was purchased and the user's purpose and manner of use must have been foreseeable by the manufacturer. Foreseeability of use may include unintended uses by the consumer if such use was reasonably foreseeable.

In *Thibeault*, the New Hampshire Supreme Court established the defense of "plaintiff's misconduct," a defense somewhat analogous to comparative negligence in negligence cases. "Plaintiff's misconduct" includes product misuse, abnormal use, as well as concepts of negligence, assumption of the risk, and proceeding to encounter a known danger.

Plaintiff's misconduct is a comparative concept in strict liability and a jury will compare the causal effect of the product's defect with the plaintiff's misconduct and allocate the fault accordingly. A verdict for the plaintiff is reduced by his percentage of comparative fault just as in a comparative negligence setting.

New Hampshire therefore recognizes the concept of strict liability and while it endorses the Restatement of Torts § 402-A, New Hampshire rejects the philosophy that strict liability is a tool of social engineering and that manufacturers should be required to bear the entire risk and costs of injuries caused by products. Strict liability is not a no-fault system of compensation, but rather in New Hampshire is based upon the important elements of fault and responsibility.

Case selected and text written by Richard E. Mills of Devine, Millimet & Branch, Victory Park, 111 Amherst Street, P.O. Box 719, Manchester, NH 03105. Telephone: (603) 669-1000.

Editor: Beth A. Hamilton
Illustrated and produced by Triodyne Graphic Communications Group.

DESIGN METHODOLOGY FOR PREDICTING ERGONOMIC GRIP STRENGTH*

Dennis B. Brickman, P.E.
Triodyne Incorporated
Niles, Illinois

ABSTRACT

A design methodology has been developed to assist bioengineering practitioners in effectively evaluating ergonomic grip strength data. The methodology employs a set of modifying factors to estimate the hand grip strength of a population in an explicit form. The introduced grip strength modification factor approach allows designers and researchers to predict the grip strength of individuals and collections of homogeneous distributions in various situations.

INTRODUCTION

Since the interdisciplinary ergonomic literature of the world reports human grip strength in dissimilar units such as kilograms, kilopascals. millimeters of mercury, pounds, and kiloponds, it is necessary to formulate a design methodology so that bioengineering practitioners can utilize the data effectively. To account for the most important conditions that affect the endurance limit of a mechanical element, Shigley employs a variety of modifying factors, each of which is intended to account for a single effect[1]. Based on this type of approach, an engineering design methodology for the evaluation of ergonomic grip strength has been developed utilizing the correction factor approach[2].

HAND GRIP STRENGTH MODIFYING FACTORS

Embracing the modification factor approach, the prediction of hand grip strength can be stated in the following form:

$$S_h = k_c\, k_t\, k_a\, k_p\, k_g\, k_s\, k_m\, S'_h \qquad (1)$$

where
- S_h = hand grip strength of population
- S'_h = hand grip strength of test sample
- k_c = characterization factor
- k_t = time of day factor
- k_a = altitude factor
- k_p = position factor
- k_g = glove factor
- k_s = support factor
- k_m = miscellaneous effects factor

Since the prediction of hand grip strength is stochastic in nature, as opposed to deterministic, all of the k factors are random variables. Modifying factors used in equation (1) are based upon the engineering, ergonomic, medical, and biological literature and are normalized for the characteristics of the test sample as defined in the subsequent sections.

Characterization Factor k_c

Age, sex, and handedness are the elements that comprise the characterization factor. The characterization factor is normalized for 22-year old right-handed males and is presented in Fig.1[3].

The characterization factor reflects that hand grip is weaker for older people, females, and left-handed people compared with the test sample.

Time of Day Factor k_t

Hand grip strength tests of the sample were performed between 9:00 a.m. and 8:00 p.m. The time of day factor adjusts the grip strength of individuals at times other than 9:00 a.m. to 8:00 p.m. and is depicted in Figure 2[4].

Figure 2 demonstrates that there is a dramatic drop in grip strength in the early morning or late evening compared with the late morning and early afternoon.

Altitude Factor k_a

Grip strength data of the test sample was acquired at an elevation close to sea level. The altitude factor takes into consideration human grip strength at elevations above sea level and is presented in Figure 3[5].

Figure 3 shows that altitude starts to have a significant adverse affect on grip strength above 5000 m.

Position Factor k_p

All of the subjects in the test sample were sitting during the hand grip experiments. The age dependent position factor modifies the grip strength of people in the upright and supine positions as illustrated in Figure 4[6].

Figure 4 indicates that hand grip is stronger in the upright position and weaker in the supine position compared with the sitting position for all ages.

Glove Factor k_g

All of the grip strength tests were conducted while the sample subjects were bare-handed. The glove factor[7] for 5 different gloves is given by equation (2):

$$k_g = \begin{cases} 1.000 & \text{if no glove} \\ 0.927 & \text{if cotton glove} \\ 0.880 & \text{if nylon and steel glove} \\ 0.873 & \text{if leather glove} \\ 0.842 & \text{if steel mesh glove} \\ 0.832 & \text{if leather and cotton glove} \end{cases} \qquad (2)$$

* Reprinted from *Advances in Bioengineering - 1992*, BED - v. 22 (1992): 517-519, with the kind permission of the American Society of Mechanical Engineers.

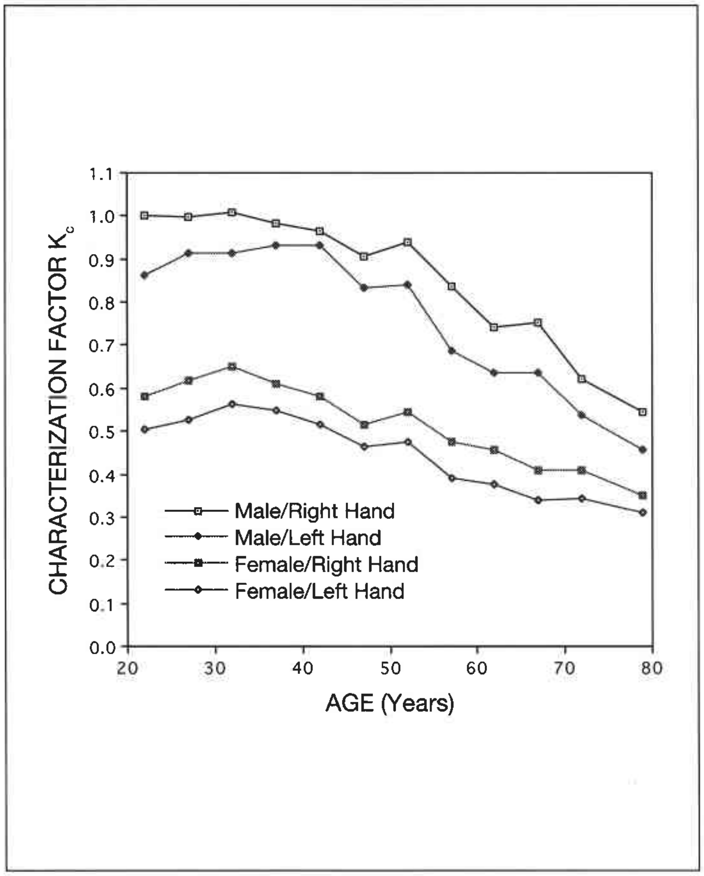

Figure 1. Characterization factor k_c

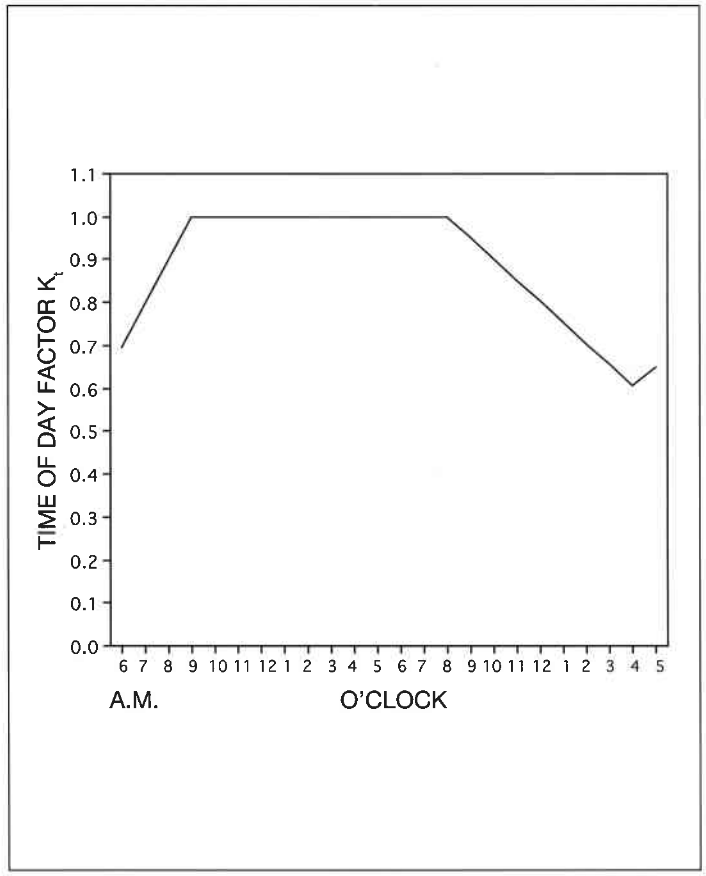

Figure 2. Time of day factor k_t

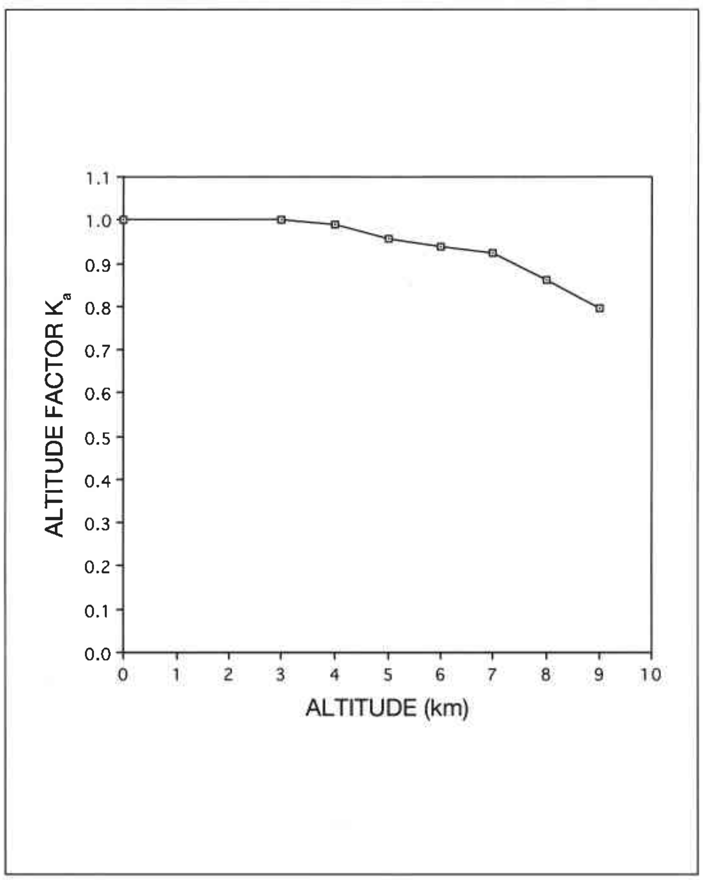

Figure 3. Altitude factor k_a

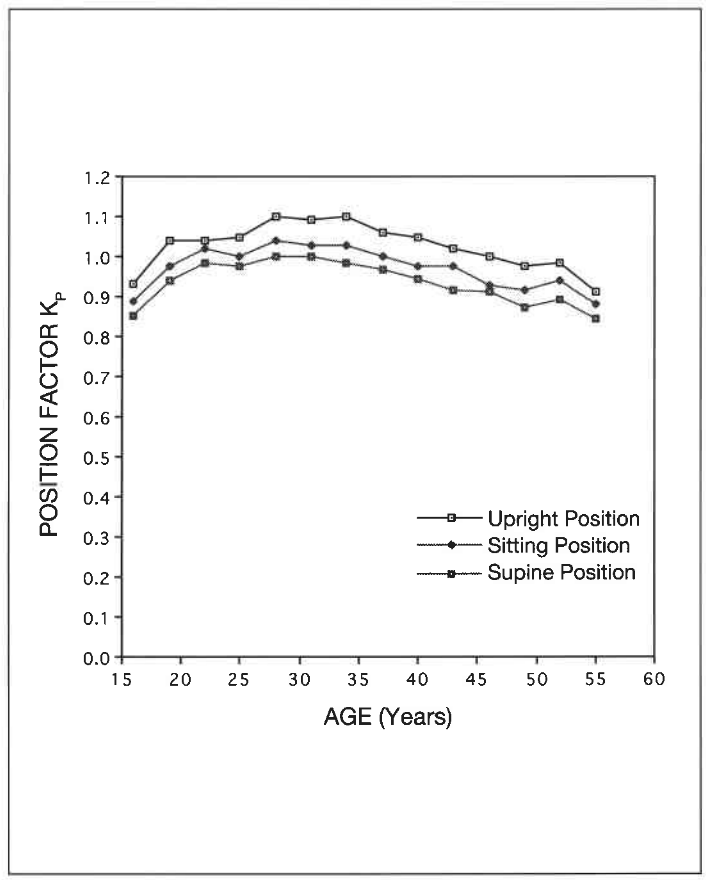

Figure 4. Position factor k_p

The amount of reduction in grip strength of people who wear gloves depends on the thickness, suppleness, tenacity, and snugness of the gloves.

Support Factor k_s

The arms of the subjects participating in the hand grip experiments were unsupported. The support factor[8] is expressed by equation (3):

$$k_s = \begin{cases} 1.000 \text{ if arm is unsupported} \\ 0.939 \text{ if arm is supported} \end{cases} \quad (3)$$

There appears to be a relatively slight decrease in grip strength when a person's arm is supported.

Miscellaneous Effects Factor k_m

A miscellaneous effects factor is included to account for those modifying factors for which insufficient information is available in the literature or for the test sample. Grip size, oxygen, temperature, fatigue, hypnosis, diet, training, wrist and forearm position, and smoking would fall into the category of the miscellaneous effects factor. Presently actual values for the oxygen, temperature, hypnosis, diet, training, and smoking factors are very difficult to obtain based upon the available ergonomic grip strength literature.

CONCLUSION

Presently a testing program must be conducted each time one needs to obtain an individual's grip strength under certain specified conditions. The primary contribution of this paper is the development of a design methodology employing a variety of modifying factors to assist bioengineering practitioners in effectively evaluating ergonomic grip strength data. The modifying factors approach presented in its explicit form gives designers and researchers a valuable tool for directly predicting the hand grip strength of a population based upon the hand grip strength data from a test sample. Applications of the modifying factors design engineering methodology described in the referenced literature include predicting maximum activation forces for airplane emergency exits and portable electric hand drills.

REFERENCES

1. Shigley, J.E. and Mischke, C.R., *Mechanical Engineering Design*, 5th ed., New York, McGraw-Hill, 1989, pp. 282-293.
2. Brickman, D.B., "Use of Extreme Value Statistics in the Characterzation of Ergonomic Strength Data," Master's Thesis, Northwestern University, May 1989.
3. Mathiowetz, V., et al., "Grip and Pinch Strength: Normative Data for Adults," *Archives of Physical Medicine and Rehabilitation* vol. 66, No. 2, (Feb. 1985): 69-74.
4. Wright, V., "Factors Influencing Diurnal Variation of Strength of Grip," *Research Quarterly* vol. 30, No. 1 (March 1959): 110-116.
5. Ruff, S. and Strughold, H., *Compendium of Aviation*, Washington, DC, Allen Property Custodian, 1942, pp. 32-34, 67-69.
6. Teraoka, T., "Studies on the Peculiarity of Grip Strength in Relation to Body Positions and Aging," *Kobe Journal of Medical Sciences* vol. 25, No. 1 (March 1979): 1-17.
7. Cechnan, D.J., et al., "An Analysis of Grasp Force Degradation with Commercially Available Gloves," *Proceedings of the Human Factors Society 30th Annual Meeting* vol. 2 (1986): 852-855.
8. Swanson, A.B., Matev, I.B., and deGroot, G., "The Strength of the Hand," *Bulletin of Prosthetics Research* BPR 10-14 (Fall 1970): 145-153.