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Influence of Age, Gender, and Blood-Alcohol Concentration on the Disappearance Rate of Alcohol from Blood in Drinking Drivers

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ABSTRACT: The rate of disappearance of alcohol from the blood (β-slope) was determined in drinking drivers by taking two blood samples about 60 min apart (mean 68 min, span 30 to 120 min). The results were compared for men and women as a function of their age and the prevailing blood-alcohol concentration (BAC). The material consisted of 1090 double blood samples from 976 men and 114 women with mean age 36.6 ± 12.9 *y* (± SD) and 38.0 ± 12.3 *y* (± SD), respectively. The mean BAC for the male DUI suspects was 1.88 ± 0.748 mg/mL (± SD) compared with 1.86 ± 0.702 (± SD) for the females. The relationship between β-slope (*y*) and BAC (*x*) was $y = 0.175 + 0.009x$ with a small positive correlation ($r = 0.13$) and standard error estimate (s_{yx}) of 0.049 mg/mL. The mean β-slope for female DUI suspects was 0.214 ± 0.053 mg/mL/h (± SD), compared with 0.189 ± 0.048 mg/mL/h in the male suspects, and this small difference was statistically highly significant ($t = 5.21$, $p < 0.001$). The overall mean rate of alcohol elimination from blood in drinking drivers was 0.191 ± 0.049 mg/mL/h (± SD), and the 95% limits of agreement (LOA) spanned from 0.09 to 0.29 mg/mL/h. The value of the β-slope was slightly steeper starting from a high initial BAC but was not much influenced by the person's age.

KEYWORDS: forensic science, forensic toxicology, alcoholics, analysis, blood-ethanol, β-slope, ethanol metabolism, elimination, drunk drivers, pharmacokinetics

The rate of disappearance of alcohol from the blood (β-slope) is an important parameter with special significance whenever the pharmacokinetics of ethanol are considered (1). The β-slope, which is sometimes referred to as the alcohol burn-off rate, has been much discussed and debated in litigation concerning driving under the influence of alcohol (DUI), particularly when forward or backward extrapolations of a person's BAC are required by law (2–4). The customary way to determine the β-slope involves making controlled drinking experiments with healthy volunteers who consume a known moderate amount of alcohol on an empty stomach (5–7). From the BAC measurements made every 30 to 60 min during the postabsorptive phase, the rate of disappearance of alcohol from the bloodstream is easily calculated (7). Many studies have shown that the mean β-slope for moderate drinkers is between 0.10 and 0.20 mg/mL/h (mean 0.13 to 0.15 mg/mL/h) when the dose of alcohol is consumed in the morning after an overnight fast (5,7,8). Women tend to have a slightly steeper β-slope compared with men according to several controlled studies (5,6,9,10).

It is widely known that heavy drinkers and alcoholics develop metabolic tolerance during a drinking binge and alcohol is eliminated faster compared with those who only drink occasionally (10–14). One recent study in chronic alcoholics undergoing detoxification reported a mean β-slope of 0.22 mg/mL/h with a range from 0.13 to 0.36 mg/mL/h (11). This faster rate of ethanol disposal in recently drinking alcoholics stems from microsomal enzymes (P4502E1) being engaged in the oxidation processes in addition to hepatic class I alcohol dehydrogenase (ADH) (3,15). The P4502E1 system has a higher k_m for oxidation of ethanol (0.60 to 80 mg/mL) compared with ADH (0.05 to 0.10 mg/mL) and, more importantly, the microsomal enzymes become more effective after a period of heavy drinking as a result of an increased synthesis of the enzyme (16,17). However, after a few days of abstinence, it seems that alcoholics lose their ability to burn off alcohol faster than moderate drinkers (18–20).

The β-slope in drinking drivers has never been determined in an unequivocal way, that is, by evaluating BAC profiles for a large segment of the postabsorptive period. Instead, β-slopes in drinking drivers have been estimated by taking two blood samples about 60 min apart (21,22). The results obtained in this way reflect the disappearance rate of alcohol from the blood over the time period studied, and the existence of zero-order or saturated Michaelis-Menten kinetics means that the β-slopes should remain the same for most of the postabsorptive period (3,7,21,22). However, not all DUI suspects will have reached the postpeak phase at the time of taking blood samples, and relatively shallow β-slope, or no change in BAC at all, might be observed (3). Others might find themselves on a BAC diffusion plunge when the first sample of blood was taken leading to an abnormally high value for the β-slope (3,21). Nevertheless, by examining a sufficiently large material of double blood samples, a reliable estimate of the mean velocity of alcohol elimination from the bloodstream can be obtained in DUI suspects.

In this paper, we have determined the rate of alcohol elimination from blood (β-slope) in over 1000 individuals apprehended for DUI in Sweden. The results were evaluated as a function of the person's age, gender, and the prevailing blood-alcohol concentration.

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Material and Methods

The police authorities in Sweden frequently take two separate samples of venous blood from drinking drivers, particularly if the driver is not arrested at the wheel and therefore has the opportunity to claim drinking alcohol after driving. Alleged drinking after the offense, the hip-flask ploy, is a common defense tactic in Sweden as well as in other countries (23). The allegation of drinking after the offense might be confirmed or challenged depending on whether the BAC increases or decreases between the times of sampling blood. However, interpreting the position of the BAC curve based on only two randomly timed specimens of blood is fraught with difficulties and is not a recommended practice (3). Nevertheless, the police persisted with submitting double blood specimens for quantitative determination of alcohol. The first sample of blood is normally taken about 60 to 90 min after the person is arrested for DUI.

We collected together the results from analyzing a large number of double blood samples at the National Laboratory of Forensic Chemistry in Linköping, Sweden. When the BAC in the first sample was below 0.20 mg/mL or above 3.5 mg/mL, these specimens were eliminated leaving a total of 1090 double blood samples from 976 men and 114 women. The concentration of alcohol in blood samples was determined by headspace gas chromatography as described elsewhere, and the coefficient of variation of the method of analysis was less than 1% (24). This high analytical precision means that the changes in BAC over time are not confounded by inherent analytical sources of variation (25). The mean of triplicate determinations on each blood specimen was used to calculate the β-slope as follows:

$$\beta_{slope} = (BAC_1 - BAC_2)/(t_2 - t_1)$$

All original BAC values were converted from milligram/gram concentration units to milligram/millilitre units by multiplying each result by 1.055, which is the average density of whole blood. The statutory alcohol limits for driving in the Scandinavian countries and in Germany are defined in terms of weight of alcohol per weight of whole blood (mg/g or g/kg). The average time between taking the first and second sample of blood was 68 min spanning from 30 to 120 min. The vast majority of double blood samples (75%) were obtained between 47 and 84 min apart.

Results

The mean age of the 976 men was 36.6 ± 12.9 *y*, and this was not significantly different from the 114 women 38.0 ± 12.3 *y* ($t = 0.73$, $p > 0.05$). The age distributions are shown in Fig. 1 in which it can be seen that the age of the men tended to peak between the ages 20–29 years (29%) and then tail off towards the age of 75 years. By contrast, women showed no marked peak in their age distribution but were more inclined to be middle aged when apprehended for DUI. The proportion of female suspects aged 40–50 years was 29% compared with 21% in the male DUI suspects.

The frequency distribution of β-slopes is shown in Fig. 2. The mean was 0.191 mg/mL/h, standard deviation 0.049, coefficient of variation 25%, skewness 0.647, and kurtosis 2.17 indicating a fairly good overall fit to the normal distribution. The mean β-slope in men was 0.189 ± 0.048 mg/mL/h ($N = 976$) compared with 0.214 ± 0.053 ($N = 114$) for the women, and this small gender-related difference was statistically highly significant ($t = 5.21$ $p < 0.001$). There were 24 individuals with β-slopes less than 0.10 mg/mL/h (mean 0.074), and BAC in the first sample of blood was 2.21 mg/mL on average, being significantly higher than the mean of 1.87 mg/mL for the material as a whole.

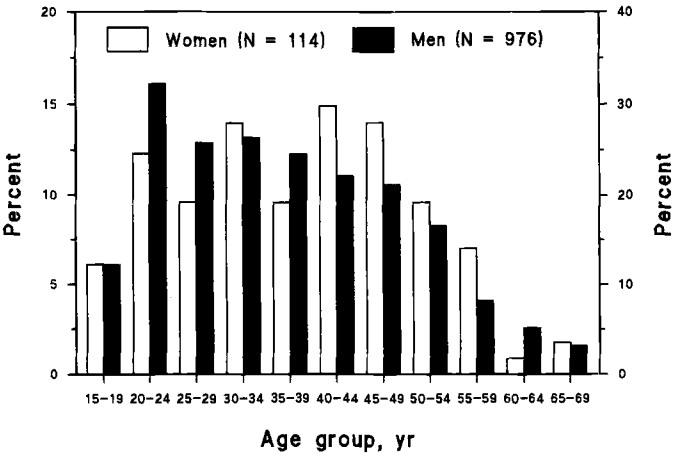

FIG. 1—*Frequency distribution of age for male and female DUI suspects apprehended in Sweden.*

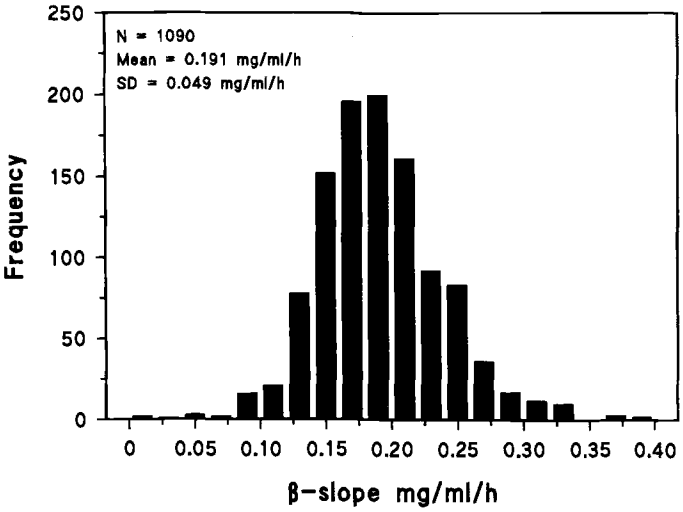

FIG. 2—*Frequency distribution of the rate of disappearance of alcohol from blood (β-slope) in drinking drivers as derived from analysis of two blood samples taken approximately 1 h apart.*

Figure 3 shows the β-slopes plotted as a function of age for male and female DUI suspects separately. The women maintained a faster rate of disappearance of alcohol from blood in all age groups studied. Table 1 gives a more detailed breakdown of β-slopes as a function of age. The 95% limits of agreement gives a good indication of the magnitude of variation within each age group. However, for some age groups, there were not enough women to allow making this calculation.

Figure 4 shows a scatter plot of β-slope plotted against BAC in the first blood sample. A very weak correlation was found ($r = 0.13$) which speaks against any strong association between burn-off rate and BAC. The regression equation was y (β-slope) $= 0.175 + 0.009x$ (BAC). Table 2 presents a more detailed breakdown of β-slopes according to BAC subdivided at intervals of 0.5 mg/mL. The mean β-slope was slightly steeper when the mean BAC was above 1.0 mg/mL compared with below 1.0 mg/mL.

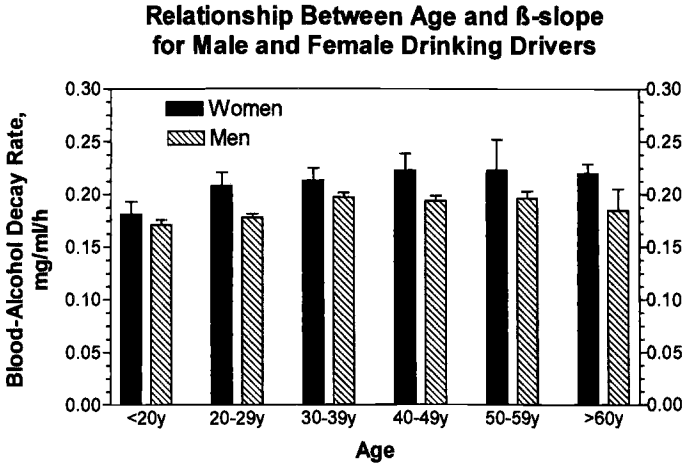

FIG. 3—*Rate of disappearance of alcohol from blood in male and female drinking drivers plotted as a function of their age.*

TABLE 1—*Disappearance rate of alcohol from blood (β-slope) arranged according to the blood-alcohol concentration for men and women drinking drivers. Values for eight male subjects with BAC > 3.5 mg/mL were omitted.*

Span of BAC mg/mL	Subjects	Number of Specimens	β-slope mg/mL/h Mean ± SD	95% Limits of Agreement
0.0–0.49	Men	27	0.165 ± 0.030	0.105–0.225
	Women	5	0.159 ± 0.030	0.099–0.219
	Total	32	0.163 ± 0.029	0.105–0.221
0.5–0.99	Men	81	0.172 ± 0.035	0.102–0.242
	Women	8	0.185 ± 0.028	0.129–0.241
	Total	89	0.173 ± 0.035	0.103–0.243
1.0–1.49	Men	147	0.183 ± 0.042	0.099–0.267
	Women	10	0.211 ± 0.038	0.135–0.287
	Total	157	0.185 ± 0.043	0.099–0.271
1.5–1.99	Men	224	0.191 ± 0.050	0.091–0.291
	Women	31	0.223 ± 0.050	0.123–0.303
	Total	255	0.195 ± 0.051	0.093–0.297
2.00–2.49	Men	252	0.189 ± 0.043	0.103–0.275
	Women	31	0.217 ± 0.055	0.107–0.327
	Total	283	0.192 ± 0.045	0.102–0.282
2.50–2.99	Men	146	0.194 ± 0.049	0.096–0.292
	Women	24	0.222 ± 0.059	0.104–0.340
	Total	170	0.198 ± 0.052	0.094–0.302
3.00–3.49	Men	91	0.207 ± 0.062	0.083–0.331
	Women	5	0.206 ± 0.064	0.078–0.334
	Total	96	0.207 ± 0.064	0.079–0.335

Discussion

The very high mean BAC in both the male (1.88 ± 0.748 mg/mL) and the female DUI subjects (1.86 ± 0.702 mg/mL) indicates that these individuals have problems with their drinking, and many are chronic alcoholics. This suggests that the β-slopes in DUI suspects should agree more closely with values seen in alcoholics during detoxification rather than in healthy volunteers who participate in controlled drinking studies in the laboratory (3,11).

In the present work, we have assumed that all individuals have reached the postpeak stage of alcohol metabolism at the time of taking the first blood sample. This assumption is not unreasonable considering that about 94 min had elapsed after they were apprehended for DUI. This is also supported by hundreds of bolus dose drinking experiments and a few controlled studies involving

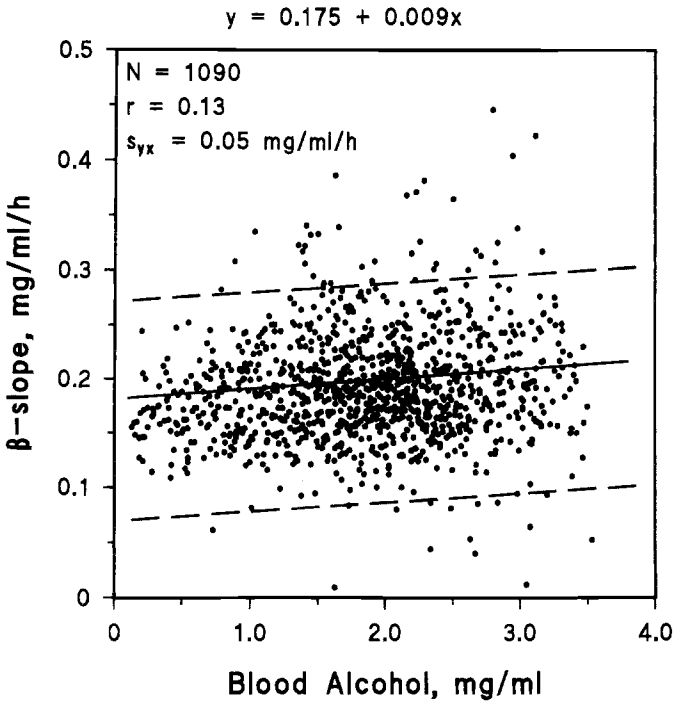

FIG. 4—*Scatter plot of the rate of disappearance of alcohol from blood (β-slope) as a function of the mean blood alcohol concentration. The regression line (solid) and 95% limits for a single new observation (broken lines) are shown.*

prolonged heavy drinking (26,27). The β-slope was less than 0.10 mg/mL/h for 24 individuals (2.2%), and this might indicate a slow absorption phase or reaching a BAC plateau during the sampling interval. Accordingly, these shallow β-slopes are not accurate estimates of the rate of disappearance of alcohol from blood because absorption and distribution of alcohol are probably incomplete (3).

The position of the blood-alcohol curve when drinking drivers are apprehended has never been determined in an unequivocal way, that is, by taking a long series of consecutive samples of blood or breath. However, Zink and Reinhardt (27) conducted an interesting study in which people drank huge amounts of alcohol for 6 to 10 h and venous blood was sampled during and after drinking at 15 min intervals. This kind of prolonged ingestion of alcohol should resemble the drinking habits of many DUI suspects who eventually reach very high BAC. The results of the study showed that most subjects had already reached their peak BAC before finishing the last drink, and all of them had peaked within 50 min after end of drinking. Unless a DUI suspect consumes alcohol when still driving, it is safe to assume that the peak BAC has been reached by the time samples of blood are taken for forensic purposes. The β-slopes reported here are therefore reliable estimates of alcohol burn-off rate in this population of heavy drinking men and women.

The small gender-related differences in β-slopes for DUI suspects support earlier results from several controlled drinking experiments in men and women as was first reported by Widmark (5) and later confirmed by Osterlind et al. (6). It is important to realize that the magnitude of the β-slope not only reflects the activity of alcohol-metabolizing enzymes, but also depends to some extent on the volume of distribution of alcohol and therefore the proportion of body water (14). Those people with a relatively small volume of distribution, e.g., women compared with men or elder men compared with younger men tend to have slightly steeper β-slopes

TABLE 2—*Rate of disappearance of alcohol from blood (β-slope) arranged according to the age of male and female drinking drivers. Values for eight men aged over 70 years were omitted.*

Age Span Years	Subjects	Number of Specimens	β-slope mg/mL/h Mean ± SD	95% Limits of Agreement
15–19	Men	60	0.172 ± 0.039	0.133–0.211
	Women	7	0.181 ± 0.031	0.119–0.243
	Total	67	0.173 ± 0.038	0.097–0.249
20–24	Men	158	0.179 ± 0.037	0.105–0.253
	Women	14	0.196 ± 0.041	0.114–0.278
	Total	172	0.181 ± 0.037	0.107–0.255
25–29	Men	126	0.177 ± 0.044	0.089–0.265
	Women	11	0.222 ± 0.051	0.120–0.324
	Total	137	0.181 ± 0.046	0.089–0.273
30–34	Men	129	0.193 ± 0.054	0.085–0.301
	Women	16	0.214 ± 0.053	0.108–0.320
	Total	145	0.195 ± 0.055	0.085–0.305
35–39	Men	120	0.199 ± 0.051	0.097–0.301
	Women	11	0.213 ± 0.034	0.145–0.281
	Total	131	0.201 ± 0.050	0.101–0.301
40–44	Men	108	0.193 ± 0.043	0.107–0.279
	Women	17	0.209 ± 0.074	0.061–0.357
	Total	125	0.195 ± 0.048	0.099–0.291
45–49	Men	103	0.195 ± 0.052	0.091–0.299
	Women	16	0.237 ± 0.059	0.119–0.355
	Total	119	0.201 ± 0.055	0.091–0.311
50–54	Men	81	0.196 ± 0.053	0.090–0.302
	Women	11	0.210 ± 0.032	0.146–0.274
	Total	92	0.198 ± 0.051	0.096–0.300
55–59	Men	40	0.194 ± 0.050	0.094–0.294
	Women	8	0.233 ± 0.061	0.111–0.355
	Total	48	0.201 ± 0.054	0.093–0.309
60–64	Men	25	0.195 ± 0.053	0.089–0.301
	Women	1	0.275 +++++	+++++
	Total	26	0.198 ± 0.054	0.090–0.306
65–69	Men	16	0.193 ± 0.071	0.051–0.335
	Women	2	0.178 +++++	+++++
	Total	18	0.191 ± 0.074	0.043–0.339

(14,28). A given concentration of alcohol in blood can seemingly be cleared faster from a smaller volume than from a larger volume. This suggests that the product of β-slope and volume of distribution (Widmark's "r") should be approximately the same regardless of sex and age (28–30).

The finding of steeper β-slopes in drinking drivers (0.19 mg/mL/h) compared with moderate drinkers (0.13 to 0.15 mg/mL/h) is easily explained by overrepresentation of heavy drinkers and alcoholics among the DUI suspects. These individuals have acquired an enhanced capacity to dispose of ethanol because microsomal enzymes (P4502E1) are activated as a consequence of regular heavy drinking. When the initial BAC was below 1.0 mg/mL, the average β-slope was 0.175 ± 0.0364 (N = 155) compared with 0.194 ± 0.0257 (N = 935) when the BAC exceeded 1.0 mg/mL; this difference was statistically highly significant (t = 7.9, $p < 0.001$). Those apprehended DUI suspects with BAC less than 1.0 mg/mL might have been engaged in moderate acute intake of alcohol without the P4502E1 enzymes becoming boosted. This could explain the smaller β-slopes at relatively low BAC compared with those having very high initial BAC because of prolonged heavy drinking.

The rate of disappearance of alcohol in DUI suspects based on double blood samples has been investigated in several earlier studies (31–33). The overall results from evaluating several thousand DUI suspects agree well with the average β-slope of 0.19 mg/mL/h reported here. In conclusion a mean β-slope of 0.19 mg/mL/h can be considered a reliable average value for the disappearance rate of alcohol in this population of drinkers (DUI suspects). However, because of individual variations in activity of alcohol metabolizing enzymes, the 95% limits of agreement could span from 0.09 to 0.29 mg/mL/h. These limits should be used when expert witnesses are asked to speculate about a person's BAC some time before sampling blood. Reports of very low β-slopes (< 0.08 mg/mL/h) probably reflects some weakness in the experimental design such as giving a very low dose of alcohol, insufficient number of blood samples, existence of a prolonged absorption phase, or distribution plateau.

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