Predictors of Error in Estimates of Blood Alcohol Concentration: A Replication*

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ABSTRACT. Objective: To identify predictors of error in estimated blood alcohol concentration (eBAC) in a sample of bar patrons. **Method:** Six hundred sixty-six patrons (43.6% female) were randomly sampled from 32 bars. Patrons were asked to provide a breath sample into a handheld breath alcohol concentration test unit upon entrance and exit from the bar. Patrons also completed a brief survey at entrance and exit. For analyses, this sample was stratified by whether patrons consumed alcohol before attending the bar. Estimates of BAC were calculated using Matthews and Miller's formula (1979). A three-category dependent variable was created based on the estimation accuracy of eBAC relative to breath alcohol concentration: accurate (within .02), underestimate of BAC, and overestimate of BAC. **Results:** Of those that drank before arriving at the bar, 29% of eBACs were accurate, 32.3% were underestimates, and 38.8% were overestimates. For those who drank only at the bar, 42.0% were accurate, 20.8% were underestimates, and 37.7% were overestimates. Among those who drank before attending the bar, the number of drinks consumed before attending the bar was significantly related to eBAC underestimate. Among those who drank only at the bar, predictors of overestimate included being female, drinking more, and drinking longer. **Conclusions:** The accuracy of eBAC is poor at best. In an earlier study of parties, eBACs were often underestimated; in the bar setting, eBACs were often overestimated. More research is needed to understand the role of setting on eBAC calculations. (*J. Stud. Alcohol Drugs* **70:** 683-688, 2009)

THE BULK OF THE EPIDEMIOLOGICAL literature on alcohol consumption is based on self-reports of drinking quantity, frequency, variability, or heavy episodic drinking (Gruenewald and Nephew, 1994; Wechsler et al., 2002). Such measures require respondents to recall the number of drinks they consumed on single or multiple occasions over a specified period (typically 2 weeks to 1 month). The reliability and validity of such measures are limited by the respondents' ability to accurately recall the number of drinks they consumed and to base this retrospective count on standard drink sizes.

The National Institute on Alcohol Abuse and Alcoholism (NIAAA) Advisory Council recently recommended that definitions of heavy episodic drinking include some reference to time and blood alcohol concentration (BAC): Heavy episodic drinking "is a pattern of drinking alcohol that brings blood alcohol concentration to .08 gram-percent or above. For a typical adult, this pattern corresponds to consuming 5 or more drinks (male), or 4 or more drinks (female), in about 2 hours" (NIAAA, 2007, p. 3). Consistent with this notion, Kypri et al. (2005) suggested estimates of blood alcohol concentration (eBAC) as a more precise indicator of problem alcohol consumption than standard quantity–frequency measures, which have low specificity relative to breath estimates of blood alcohol concentration (BrAC; Lange and Voas, 2001; Thombs et al., 2003). Developed under laboratory conditions, Widmark's (1932) original eBAC algorithm for discrete drinking episodes has been significantly modified twice (Matthews and Miller, 1979; Watson et al., 1981; Widmark, 1932). In its original form, the Widmark formula included terms for body weight, body mass, and time as they relate to BAC. The later variations correct for gender differences in the metabolism of alcohol.

The continuous eBAC construct has been used as an outcome measure in a number of studies (Alexander and Bowen, 2004; Andersson et al., 2007; Caudill et al., 2000, 2006; Demmel et al., 2004; Handmaker et al., 1999; Hansson et al., 2007; Harding et al., 2001a,b; Kypri et al., 2005, 2007; Kypri and Stephenson, 2005; Perkins et al., 2001; Stahlbrandt et al., 2007; Turner et al., 2004; Wilke et al., 2005). Two recent field studies (Clapp et al., 2006; Hustad and Carey, 2005) employed measures of BrAC to estimate the validity of self-reports used to compute eBAC. Hustad and Carey (2005) reported that time spent drinking, number of drinks consumed, gender, and year in school were all predictive of eBAC − BrAC discrepancies. In an examina-

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tion of data collected at college student parties, Clapp et al. (2006) reported that eBAC and BrAC were moderately and positively correlated ($r = .35, p < .01$). Using multinomial hierarchical modeling, Clapp et al. found that environmental factors such as party size and having many people intoxicated predicted both overestimates and underestimates of BrAC relative to eBAC. The finding that environmental factors influenced error in eBAC − BrAC discrepancies suggests that the contextual factors in which alcohol consumption occur should also be factored into calculations of eBAC whenever possible.

This article expands on the previous work done by Clapp et al. (2006) by examining eBAC − BrAC accuracy using two groups of bar patrons: those who drank before arriving at a bar and those who did not pre-drink. The impact of pre-bar drinking contexts on measures of eBAC was evaluated with the participants who consumed alcohol before arriving at the bar, and the influence of bar characteristics on the accuracy of eBAC was assessed in the participants who consumed alcohol exclusively in the bar. Specifically, we address the following research questions:

(1) What is the correlation between eBAC and BrAC among bar patrons?

(2) What are the individual predictors of eBAC − BrAC discrepancies?

(3) What are the pre-bar drinking predictors of eBAC − BrAC discrepancies?

(4) What are the bar-specific predictors of eBAC − BrAC discrepancies?

Method

Sample

BrAC values were collected with survey measures at entrance and exit from participants ($n = 666$) who reported drinking before coming to the bar or "pre-bar drinkers" ($n = 507$) and a group who did not drink before coming to the bar or "bar-only drinkers" ($n = 159$).

Procedure

Participants were randomly selected before entering the bar. The study was described to potential participants, and they were provided with an informed consent document and asked to verbally consent to participate in the study. Participants were provided with a card and a unique identification number so that they could withdraw consent at any time. All subjects were at least 18 years of age. Because of minimum drinking age laws, we assumed that all patrons would be at least 21 years of age. It was possible, however, that those younger than age 21 could access bars with fake or altered identification. Individuals with obvious signs of intoxication (swaying, slurred speech, etc.) were not included in the study. Participants were asked to complete survey items and provide a breath sample upon entrance and exit from the bar. Breath samples were collected using a handheld BrAC test unit (CMI Intoxilyzer SD-400; CMI, Inc., Owensboro, KY). The entrance survey items included demographics (gender and weight). The exit survey items included length of drinking event in minutes calculated from when the individual first started drinking that day; number of drinks consumed before coming to the bar *and/or* at the bar; places of drinking before coming to the bar (e.g., my house, friend's house, bar, or restaurant); types of drinks consumed before coming to the bar *and/or* at the bar (e.g., beer, wine, shots of distilled spirits, or mixed drinks); and methods of transportation to the bar (e.g., drove myself, rode with someone else, walked, public transportation, etc.). In a past study (Clapp et al., 2009), we found that measuring BrAC before entrance to the bar had no impact on exit BrAC.

Environmental characteristics of the bar were measured by a pair of pseudo-patrons. The patrons observed whether there was a cover charge; whether the bar was crowded; whether overpouring of drinks was taking place; whether food was available; the number of people in the bar; and the general location of the bar (e.g., beach, downtown, or college area). Kappa for agreement between pseudo-patrons was high, ranging from .80 to 1.00 on 75% of the measures (Clapp et al., 2007). For these analyses, we used reports from the primary observer.

Estimated BAC was calculated from the survey data using Matthews and Miller's (1979) formula ($\text{BAC} = [(c / 2) \times (\text{GC} / w)] - [\beta_{60} \times t]$). Here, BAC is blood alcohol concentration expressed in g/dl; c is the number of standard drinks reported; GC is a gender constant (9.0 for women and 7.5 for men); β_{60} is the metabolism rate of alcohol per hour (.017 g/dl); and t is the number of hours spent drinking (Matthews and Miller, 1979; the above is adapted from Hustad and Carey, 2005, p. 131). A discrepancy score (eBAC − BrAC) was computed and assigned into categories: accurate (within .02 g/dl), underestimates of BAC ($\leq$ -.02 g/dl), and overestimates of BAC ($\geq$ +.02 g/dl).

Data analysis

To replicate previous research on the accuracy of eBAC relative to BrAC (Clapp et al., 2006), multinomial logistic regression models were estimated using Stata 9.02 (StataCorp LP, College Station, TX) to examine the effects of individual and pre-bar drinking characteristics on eBAC accuracy among pre-bar drinkers. The analyses examined two outcomes of interest: (1) Logit 1, comparing "underestimate" with "accurate" categories, and (2) Logit 2, comparing "overestimate" with "accurate" categories. In the first model, a block of individual characteristics was used to predict the logit outcomes. In the second hierarchical regression model, a block of pre-bar drinking characteristics was added to the model. A chi-square difference test between Model 1 and Model 2 was used to examine whether the block of pre-bar drinking characteristics significantly contributed to the log odds of eBAC accuracy above and beyond the contribution from the block of individual-level characteristics. According to a model-building strategy for multinomial logistic regression (Hosmer and Lemeshow, 2000), all potential interaction terms (i.e., Gender × Weight, Gender × Total Number of Drinks, and Gender × Total Hours Spent Drinking) were estimated (no interactions were found to be significant and were thus excluded from the subsequent analysis). No multicollinearity among the independent variables was detected in any of the models tested. For the group of bar-only drinkers, another hierarchical multinomial logistic regression was estimated using both individual and bar characteristics as predictors.

Because participants were observed across the contexts of 30 bars, there is the potential for a violation of the independence of observations assumption that can result from the use of clustered data. As such, multilevel data analyses were estimated to determine the extent of between-level variation on outcome variables of interest. We computed a two-level hierarchical linear model (HLM), using HLM 6.02 (Scientific Software International, 2004), which found no significant variation between bars. This suggests that clustering was not a problem in this sample, and the analyses employed a standard hierarchical multinomial logistic regression strategy.

Results

Demographics of pre-bar drinkers

Table 1 presents demographic and individual characteristics of 507 participants who drank before arriving at the bar. Slightly more than half of the sample was male (56%), with a mean weight of ~160 lbs and a mean (SD) age of 24.9 (3.3) years (range: 20-47). These participants drank an average of about four standard drinks over an average of 2.5 hours before arriving at the bar. Upon entrance to the bar, the mean BrAC was .049 (.041) g/dl, and the mean eBAC was .057 (.052) g/dl. Regarding the accuracy of eBAC, 32% of the sample had a lower eBAC relative to BrAC, 29% were within the accurate range of BrAC (within ±.02 g/dl), and 39% had a higher eBAC relative to BrAC. The correlation between eBAC and BrAC for pre-bar drinkers was .353 ($p <$ .001; $n = 466$).

TABLE 1. Characteristics of the pre-bar drinkers ($n = 507$)

Characteristic	Descriptive statistic Mean (SD) or %	Range	
		Min.	Max.
Gender			
Female	43.6%		
Male	56.4%		
Age, in years	24.9 (3.3)	20	47
Weight, in pounds	159.9 (35.2)	81	340
No. of drinks before bar arrival	3.7 (2.7)	1	25
No. of hours drinking before bar arrival	2.5 (1.9)	0	10.8
Breath alcohol concentration, g/dl	.049 (.041)	.000	.197
eBAC, g/dl	.057 (.052)	.000	.380
eBAC accuracy categories			
Underestimate	32.3%		
Accurate	28.9%		
Overestimate	38.8%		

Notes: Min. = minimum; max. = maximum; eBAC = estimated blood alcohol concentration.

Individual predictors of eBAC accuracy

Table 2 presents results from the multinomial logistic regressions on eBAC accuracy for the sample of pre-bar drinkers. Model 1 reports the odds ratios (ORs) and 95% confidence intervals (CIs) for the two logit outcomes with individual characteristics as predictors. Individual predictors included in the model reflect those in the eBAC algorithm: gender, weight, number of drinks consumed and hours reported drinking (other demographics are excluded). For Logit 1, only the total number of drinks consumed before coming to the bar was significant (OR = 1.16), such that the likelihood of underestimating BAC increased by 16% for every one-drink increase before arriving at the bar. The CI suggests that a BrAC underestimate between 3% and 31% is consistent with data at the 95% level of confidence. For Logit 2, no individual characteristics were associated with the overestimation of BAC relative to BrAC.

Pre-bar drinking predictors of eBAC accuracy

Model 2 presents results from a hierarchical multinomial logistic regression that includes the block of pre-bar drinking characteristics in addition to the block of individual characteristics. The total number of drinks before the bar remained significant (OR = 1.17), but none of the pre-bar variables was related to Logit 1. However, four pre-bar characteristics related to Logit 2, which estimated the odds of overestimating BAC relative to BrAC. Here, pre-drinking at one's own house increased the likelihood of overestimating BAC by a factor of 2. Pre-bar consumption of wine, shots of distilled spirits, or mixed drinks decreased the likelihood of overestimating BAC by 60%, 55%, and 68%, respectively. The addition of the pre-bar drinking characteristics significantly increased the variance accounted for in this model, as indicated by a significant chi-square statistic comparing Model 1 with Model 2 ($\chi^2 = 35.13$, 22 df, $p = .037$).

Demographics of bar-only drinkers

Table 3 presents demographic and individual characteristics of 159 participants who only drank at the bar (i.e., endorsed no pre-bar drinking). Slightly more than half of the sample was female (57%), with a mean weight of ~156 lbs

TABLE 2. Hierarchical multinomial logistic regression on eBAC accuracy for pre-bar drinkers ($n = 507$)

	Model 1		Model 2	
Characteristic	Logit 1 (Underestim. vs accurate) OR (95% CI)	Logit 2 (Overestim. vs accurate) OR (95% CI)	Logit 1 (Underestim. vs accurate) OR (95% CI)	Logit 2 (Overestim. vs accurate) OR (95% CI)
Individual characteristics				
Gender, 1 = female	1.35 (0.70-2.59)	1.37 (0.74- 2.54)	1.19 (0.59-2.40)	1.71 (0.87-3.35)
Weight, in pounds	1.00 (0.99-1.01)	0.99 (0.98-1.01)	1.00 (0.99-1.01)	0.99 (0.98-1.00)
No. drinks	1.16* (1.03-1.31)	0.00 (0.88-1.14)	1.17* (1.02-1.33)	0.99 (0.86-1.16)
Hours spent drinking	1.16 (0.99-1.35)	1.02 (0.88-1.19)	1.15 (0.98-1.34)	1.04 (0.89-1.23)
Pre-bar characteristics				
Pre-drink at my house			1.76 (0.94-3.29)	2.00* (1.08-3.73)
Pre-drink at friend's house			1.45 (0.75-2.80)	1.81 (0.93-3.51)
Pre-drink at bar			1.47 (0.76-2.86)	1.47 (0.74-2.89)
Pre-drink at restaurant			1.28 (0.65-2.49)	1.48 (0.76-2.89)
Beer			0.82 (0.42-1.60)	0.53 (0.25-1.12)
Wine			1.24 (0.58-2.65)	0.40* (0.17-.95)
Shots			0.87 (0.46-1.67)	0.45* (0.22-.92)
Mixed drinks			1.23 (0.66-2.29)	0.32† (0.16-.67)
Methods of transportation				
Drove myself			0.84 (0.38-1.83)	0.55 (0.26-1.19)
Rode with someone else			0.70 (0.35-1.41)	0.65 (0.33-1.26)
Walked			1.05 (0.46-2.39)	0.69 (0.31-1.55)
Taxi, bus, etc. (ref. cat.)			–	–

Notes: A response of "Accurate" was used as a reference category. Cox and Snell pseudo $R^2 = .169$. eBAC = estimated blood alcohol concentration; underestim. = underestimate; overestim. = overestimate; OR = odds ratio; CI = confidence interval; ref. cat. = reference category. $^*p < .05$; $^\dagger p < .01$.

and an average age of 24.3 (3.2) years (range: 21-39), and these participants drank an average of about four standard drinks over an average of 2.1 hours at the bar. Upon bar exit, the mean BrAC was .057 (.041) g/dl, and the mean eBAC was .076 (.065) g/dl. Regarding the accuracy of eBAC, 20% of the sample had a lower eBAC relative to BrAC, 43% were within the accurate range of BrAC (within ±.02 g/dl), and 38% had a higher eBAC relative to BrAC. The correlation between eBAC and BrAC for those who only drank at the bar was .556 ($p < .001$; $n = 148$).

TABLE 3. Characteristics of the bar-only drinkers ($n = 158$)

Characteristic	Descriptive statistic Mean (SD) or %	Range Min.	Max.
Gender			
Female	57.0%		
Male	43.0%		
Age, in years	24.3 (3.2)	21	39
Weight, in pounds	155.6 (36.8)	101	270
No. of drinks at the bar	4.0 (2.5)	1	15
No. of hours drinking at bar	2.1 (1.0)	0.25	5.50
Breath alcohol concentration, g/dl	.057 (.041)	.005	.218
eBAC, g/dl	.076 (.065)	.000	.338
eBAC accuracy categories			
Underestimate	20.3%		
Accurate	42.5%		
Overestimate	37.7%		

Notes: Min. = minimum; max. = maximum; eBAC = estimated blood alcohol concentration.

Individual and environmental predictors of eBAC accuracy

Table 4 presents the ORs from a hierarchical multinomial logistic regression of eBAC accuracy (using the two logit outcomes described previously) on a range of individual and bar characteristics for the sample of bar-only drinkers. Only the number of hours spent drinking in the bar was significantly associated with the likelihood of BAC underestimation (Logit 1: OR = 2.05, 95% CI: 1.27-3.29), such that the likelihood of underestimating BAC increased twofold for every 1-hour increase in drinking time at the bar. Three variables increased the likelihood of BAC overestimation (Logit 2): Being female increased the odds of overestimating BAC almost threefold (OR = 2.73, 95% CI: 1.28-5.82), and every one-drink increase (OR = 1.86, 95% CI: 1.46-2.37) and 1-hour increase of drinking time at the bar (OR = 2.10, 95% CI: 1.39-3.17) increased the odds of overestimating BAC twofold. A greater body weight (OR = 0.99, 95% CI: 0.98-0.99) and a beach bar location relative to a college area location (OR = 0.29, 95% CI: 0.10-0.82) were associated with a decreased likelihood of overestimating BAC.

Discussion

Recent epidemiological studies on alcohol use have used measures of eBAC as a primary outcome to index levels of problematic drinking. However, eBAC has shown a rather low correspondence with BrAC. The current study assessed

Table 4. Hierarchical multinomial logistic regression on eBAC accuracy for bar-only drinkers ($n = 158$)

Characteristics	Logit 1 (Underestimate vs accurate) OR (95% CI)	Logit 2 (Overestimate vs accurate) OR (95% CI)
Individual characteristics		
Gender, 1 = female	0.83 (0.35-1.94)	$2.73^{\dagger}$ (1.28-5.82)
Weight, in pounds	1.00 (0.99-1.01)	$0.99^{\dagger}$ (0.98-0.99)
No. of drinks	1.09 (0.84-1.41)	$1.86^{\ddagger}$ (1.46-2.37)
Hours spent drinking	$2.05^{\dagger}$ (1.27-3.29)	$2.10^{\ddagger}$ (1.39-3.17)
Bar characteristics		
Cover charge, 1 = yes	1.39 (0.58-3.29)	1.72 (0.83-3.57)
Crowded, 1 = yes	1.30 (0.39-4.34)	1.14 (0.39-3.27)
Overpouring, 1 = yes	0.88 (0.37-2.08)	1.08 (0.53-2.11)
Food available, 1 = yes	0.75 (0.30-1.86)	1.20 (0.53-2.71)
Occupancy	1.00 (0.99-1.00)	1.00 (0.99-1.00)
Bar location		
Beach area	0.71 (0.19-2.72)	0.29^{*} (0.10-0.82)
Downtown area	1.86 (0.45-7.67)	1.29 (0.43-3.88)
College area (ref. cat.)	–	–

Notes: eBAC = estimated blood alcohol concentration; OR = odds ratio; CI = confidence interval; ref. cat. = reference category.
$^{*}p < .05$; $^{\dagger}p < .01$; $^{\ddagger}p < .001$.

both eBAC and BrAC among bar patrons who reported some or no pre-bar drinking and tested for previous and concurrent environmental factors associated with discrepancies between the two measures of BAC. As found previously (Clapp et al., 2006), eBAC had a relatively low correlation with BrAC measures ($r = .353$ for pre-drinkers and .556 for bar drinkers). Similar to previous research, the present study found that eBAC overestimated or underestimated rates of BrAC for the majority of participants (Carey and Hustad, 2002; Clapp et al., 2006; Hustad and Carey, 2005). The eBAC was within .02 g/dl of BrAC and was considered to be accurate for only 29% of the pre-bar drinkers and 42% of the bar-only drinkers. Even at this simplified level, the ability of eBAC to accurately capture BrAC appears somewhat poor.

For the pre-bar drinkers, the number of drinks consumed before arriving at a bar was predictive of underestimating BAC, which is consistent with the previous study on college partygoers (Clapp et al., 2006). For the bar-only drinkers, an increase in the number of drinks consumed at the bar increased the odds of overestimating BAC, whereas the more time spent drinking at the bar increased the odds of BAC inaccuracy in both directions (e.g., overestimation and underestimation relative to accurate). Female bar-only drinkers were also about three times more likely than men to have an overestimated BAC in this setting. These findings reflect important sources of individual-level error in eBAC estimation that may be the result of temporal fluctuations in alcohol consumption (and resulting metabolism) across the course of any given evening. Future research is needed to more fully evaluate the temporal factors associated with eBAC inaccuracies across contexts and gender and determine how the eBAC formula can be modified to include such factors.

Regarding contextual predictors of eBAC accuracy, the prior consumption of wine, shots of distilled spirits, or mixed drinks decreased the odds of overestimating BAC for the pre-bar drinkers. However, the opposite pattern was found for pre-drinking at one's house, which increased the odds of BAC overestimation twofold and may be a result of participants underestimating the amount of time between when they started drinking and arriving at the bar. For the bar-only drinkers, eBAC was a better predictor of BrAC, in contrast to private settings. The formal controls over drinking (i.e., alcohol is purchased) might account for better recall among patrons and more standardized drink sizes served by bar staff.

Overall, these predictors of eBAC inaccuracy provide continued evidence as to the inability of the current formula of eBAC to accurately and consistently capture the level of BAC as measured by breath samples. Future research is needed to assess whether the inclusion of both prior and current drinking context characteristics would improve the accuracy of the eBAC formula. Judging from these findings, the eBAC measure would likely be enhanced by accounting for a variety of contextual variables relevant to drinking behaviors.

This study builds on prior research that examined individual and environmental predictors of eBAC accuracy in college partygoers (Clapp et al., 2006). Unique to this study was the use of data from multiple sources, including self-report data, field observations, and biologically based BrAC samples. In contrast to our original study (Clapp et al., 2006), which found that the majority of discrepancies were related to underestimating BAC, the current study showed that contextual characteristics impacted the likelihood of overestimating BAC using the eBAC formula. A key difference was that the earlier study examined the individual and environmental characteristics of college party attendees who were an average age of ~20 years, whereas this study focused on these characteristics as they pertain to bar patrons who were an average age of 24.4 years. Although it is beyond the scope of this study to directly compare differences across these settings, the current findings reinforce the primary implication that characteristics of drinking contexts can adversely impact the accuracy of BAC estimation in college and young adult populations. Future research is needed to identify the underlying reasons for differential effects of environmental conditions on eBAC estimation. Given the ubiquity of self-report data in the drinking literature, identifying accurate indicators of problem drinking and intoxication is critical to the field. These findings highlight the importance of understanding the role that drinking environment settings play in the accuracy of BAC estimation and suggest means by which this measure might be improved. Future work is needed to conceptualize, measure, and estimate BAC in survey work. It is not surprising that eBAC formulas developed in the laboratory do not perform optimally in the field.

Research into increasing the validity of self-reports with emphasis on factors such as recall of drink size, quantity, and the like will likely improve eBAC formulas for future research.

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