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Self-Estimation of Blood Alcohol Concentration: A Review

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Abstract

This article reviews the history of blood alcohol concentration (BAC) estimation training, which trains drinkers to discriminate distinct BAC levels and thus avoid excessive alcohol consumption. BAC estimation training typically combines education concerning alcohol metabolism with attention to subjective internal cues associated with specific concentrations. Estimation training was originally conceived as a component of controlled drinking programs. However, dependent drinkers were unsuccessful in BAC estimation, likely due to extreme tolerance. In contrast, moderate drinkers successfully acquired this ability. A subsequent line of research translated laboratory estimation studies to naturalistic settings by studying large samples of drinkers in their preferred drinking environments. Thus far, naturalistic studies have provided mixed results regarding the most effective form of BAC feedback. BAC estimation training is important because it imparts an ability to perceive individualized impairment that may be present below the legal limit for driving. Consequently, the training can be a useful component for moderate drinkers in drunk driving prevention programs.

Keywords

alcohol drinking; automobile driving; blood alcohol concentration; humans

1. Introduction

Drivers are expected to make safe, rational decisions about driving after drinking, but are often unaware of alcohol-related driving laws (da Conceição, De Boni, Duarte, & Pechansky, 2012) and potential impairment below the legal limit for driving. This lack of

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Contributors

E.R. Aston conducted literature searches and wrote the first draft of the manuscript. E.R. Aston and A. Liguori edited the manuscript and wrote all subsequent drafts of the manuscript together. Both authors significantly contributed to and have approved the final manuscript.

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Conflict of Interest

All authors declare that they have no personal or financial conflict of interest.

knowledge may stem in part from unfamiliarity with the mechanisms of the blood alcohol curve. Drinkers tend to underestimate the rate of alcohol absorption and overestimate the rate of elimination (Martin et al., 1991). Such errors are potentially hazardous, as ability to drive is often decided after alcohol consumption. Incorrect estimations are further confounded by a disconnect between blood alcohol concentration (BAC) and perception of impairment (Beirness, 1987; O'Malley & Maisto, 1984; Wicki, Gache, & Rutschmann, 2000). Individuals tend to report greater impairment on the ascending limb of the blood alcohol curve, while experiencing acute tolerance to some alcohol effects at the same BAC on the descending limb. Acute tolerance, however, does not necessarily equate to recovery of driving ability (Bernosky-Smith, Shannon, Roth, & Liguori, 2011; Marczinski, Harrison, & Fillmore, 2008).

Drinking establishments generally do not provide data regarding the average number of alcoholic beverages one must consume to reach or exceed the legal limit. While drinkers are familiar with the legal limit, they are likely less aware of the relationship between quantity of alcohol and resulting BAC. Despite this, drinkers are expected to adjust their consumption accordingly if they plan to drive. Without training, drinkers are very poor estimators of BAC, and generally make inaccurate decisions about legal driving ability (Beirness, 1987; Hay, Nathan, Heermans, & Frankenstein, 1984; Lansky, Nathan, Ersner-Hershfield, & Lipscomb, 1978; Shortt & Vogel-Sprott, 1978; Wicki et al., 2000). Social drinkers, however, can acquire the ability to estimate BAC accurately by undergoing estimation training. Variants of this training have included "internal" training, "external" training, or both. Internal training includes attention to physical symptoms and subjective feelings, and association of such states with specific BAC levels measured with a breath test device (e.g., Bois and Vogel-Sprott, 1974). External training consists of information about BAC levels likely associated with specific doses of alcohol according to body weight and gender (e.g., Huber et al., 1976).

2. Methods

This article reviews the literature on controlled drinking, BAC estimation, and the impact of this estimation within naturalistic settings. The reviewed research is characterized by evaluation of BAC estimation ability, or employs BAC discrimination in therapies intended to reduce consumption. Relevant studies were identified via internet searches of electronic databases including PubMed and Web of Science. Search terms included alcohol, controlled drinking, breath alcohol, BAC, estimation, training, feedback, and discrimination. Additionally, reference sections from previous reviews of controlled drinking and BrAC estimation training were examined for relevant literature (Chase, Salzberg, & Palotai, 1984; Miller, 1983; Nathan & Lipscomb, 1979; Rowan, 1978; Shortt & Vogel-Sprott, 1981).

3. Results

3.1 Controlled Drinking in Alcoholics and Problem Drinkers

Studies of behavioral control in alcoholic drinkers do not share a commonly accepted definition of controlled drinking. Such drinking has been defined as "exerting the self-control necessary to maintain a pattern of moderate social drinking" (Lovibond and Caddy, 1970: 439), as well as "occasional consumption of alcohol without evidence of drunkenness" (Mills et al., 1971: 22). Controlled drinking is generally considered to be the ability to consume alcohol in moderation with minimal negative consequences, similar to the consummatory behavior of social drinkers. BAC estimation training was originally conceived as an important component of controlled drinking therapies for alcoholics and problem drinkers. Researchers hypothesized that incorporation of BAC discrimination training in treatment programs would enable alcoholics to monitor intoxication level,

ultimately allowing for termination of consumption at a more appropriate BAC. Lovibond and Caddy (1970) conducted seminal research utilizing BAC discrimination training to teach alcoholics to consume alcohol in a moderate fashion. During training, subjects provided estimates of BAC and received immediate feedback of actual BAC. Aversive conditioning was then implemented whereby experimental subjects experienced a strong electric shock when BAC exceeded 0.065%, while controls received non-contingent electric shocks. The authors concluded that a majority of the alcoholic subjects could be trained to estimate BAC within 0.01% of actual BAC. However, each estimate was followed by accurate feedback, arguably confounding each subsequent estimate by providing reference points for BAC estimates. Estimation accuracy quickly declines in alcoholic subjects following removal of BAC feedback (Silverstein, Nathan, & Taylor, 1974), thus their acquisition of BAC estimation remains unknown.

Caddy and Lovibond (1976) analyzed the effectiveness of each therapeutic component included in the design of their original 1970 study. The combined treatments used were parsed out and applied to three distinct groups of subjects, all of whom received BAC discrimination training. The conditions included self-regulation (self-control training), aversion (aversive conditioning), and aversion plus self-regulation (self-control training and aversive conditioning). Individuals in the aversion plus self-regulation group showed the most improvement, though only 25% of subjects were considered a complete success one year later. Subjects were considered completely successful if they were exceeding a BAC of 0.07% less than once per month, and if both the subject and therapist were satisfied with any alterations in alcohol-related behavior. This individualized approach limited the generalizability of the results. Only one of 20 enrolled subjects in the aversion therapy group was considered a success at the end of the study, and as such the authors concluded that aversive conditioning alone may not be therapeutically effective.

In response to studies that incorporated aversive conditioning, Silverstein et al. (1974) trained alcoholics to pair physiological symptoms with BAC feedback after alcohol administration. Accuracy of BAC estimations deteriorated rapidly after feedback was removed. When subjects were expected to achieve and maintain a BAC of 0.08% over 16 hours in the absence of feedback, titration ability deteriorated as well. Subjects were permitted to choose a comfortable post-study level of consumption, and at follow-up, most subjects successfully altered consumption to match these predetermined levels. An important limitation of this research is that achieving and maintaining a BAC of 0.08% for 16 hours is neither normative nor moderate drinking. Furthermore, the predetermined post-study consumption typically exceeded quantities characteristic of normative drinking (USDA and USDHHS, 2010).

Other investigators (Strickler, Bigelow, Lawrence, & Liebson, 1976) also adopted the premise that treatments involving aversive conditioning lack therapeutic value. Instead, in a novel training approach, alcoholics were encouraged to practice normative consumption behaviors. In addition to receiving training in socially acceptable drinking, subjects received feedback about BAC and were encouraged to associate BAC with internal cues. Subjects underwent therapy sessions while abstinent, practiced consuming alcohol in moderation, and were exposed to various BAC levels. Acquisition of socially acceptable drinking patterns was analyzed during a party situation. Two-thirds of the subjects drank significantly less per day at follow-up than during pre-treatment. However, these subjects were not consuming alcohol in a normative manner as they were still consuming approximately thirty drinks per week, which is more than twice the USDA standards for moderate consumption (USDA and USDHHS, 2010).

Several studies expanded the breadth of approaches to controlled drinking. A combination of viewing individualized recordings of one's own intoxicated behavior, discrimination training, forms of aversive conditioning, instruction of healthy alternative activities to drinking, and behavioral counseling resulted in consummatory reduction in approximately 63% of alcoholic subjects (Vogler, Compton, & Weissbach, 1975; Vogler, Weissbach, Compton, & Martin, 1977). However, in addition to continued uncontrolled drinking episodes, the average intake at follow-up was more than 20 drinks per week, much higher than intake of moderate drinkers. Miller (1978) compared aversive counterconditioning, behavioral self-control, and BAC discrimination training plus aversive conditioning in a sample of problem drinkers. The aversive counterconditioning procedure was unique in that subjects smelled their preferred drink and imagined drinking it without actually consuming the beverage. Subjects self-administered shocks each time they imagined consuming the drink. Self-reported weekly alcohol consumption was significantly reduced at follow-up in all three conditions, although aversive counterconditioning was the least effective condition. After treatment, subjects reported consuming an average of fourteen drinks per week, and thus exhibited moderate drinking patterns (USDA and USDHHS, 2010). This study further highlighted the importance of treating problem drinkers before they meet criteria for alcoholism.

Two subsequent studies tested the hypothesis that alcoholic subjects trained to associate interoceptive cues with socially acceptable BACs would be able to modulate alcohol consumption. In the first (Ludwig, Bendfeldt, Wikler, & Cain, 1978), subjects were instructed to titrate to and maintain socially acceptable BACs in the range of approximately 0.046% to 0.059% based on internal cues, but were unable to do so. The authors posited a neurophysiological feedback dysfunction in alcoholics that contributes to alcoholics' loss of control over consumption. The second study (Lansky, Nathan, & Lawson, 1978) compared internal and external training. Internal training consisted of listening to a relaxation tape intended to increase awareness of physical sensations and internal states, followed by completion of symptom checklists. External training included individualized explanation of the approximate alcohol absorption rate for each subject based on body weight. Only external training significantly improved estimation accuracy. However, all subjects received accurate BAC feedback during training and information about the amount of alcohol in their beverages during testing, confounding identification of the most salient training components. The moderate amount of alcohol administered in both studies also may have contributed to the alcoholic subjects' inability to estimate BAC, as the subjects were likely accustomed to higher alcohol doses. However, this theory was tested in a subsequent study via administration of high alcohol doses intended to increase BAC to 0.15% (Shapiro, Nathan, Hay, & Lipscomb, 1980). The increased doses disrupted rather than improved estimation accuracy in alcoholic subjects, suggesting that alcoholics are unable to accurately estimate BAC regardless of dose.

3.1.1. Conclusions on Controlled Drinking Studies—Many of the studies outlined in this section share methodological flaws that likely influenced results (see Table 1). These include sample sizes typically fewer than 15 subjects per condition, and attrition of at least 25% of subjects in half of the studies. Additionally, most of these investigations lacked a valid control group. Alcoholic subjects should have been compared to a sample of non-alcoholic drinkers matched on body mass index (Barquín, Luna, & Hernández, 2008) and gender (Hindmarch, Kerr, & Sherwood, 1991), which would have eliminated known confounds of reductions in consumption or acquisition of estimation ability. In many of the discussed studies, treatment was not always standardized across subjects, but tailored to fit individual goals, limiting the generalizability of results. Furthermore, while reduction of consumption reflects control over drinking, many subjects who continued drinking beyond normative levels would still be considered problem drinkers, if not alcoholics, at the end of

treatment (Miller, 1983). Many of these studies tested the hypothesis that training in BAC estimation would lead to reductions in consumption. Unfortunately, these investigations indicated that alcoholics cannot estimate BAC accurately, and discrimination training was ineffective in reducing alcoholic consumption to socially acceptable levels. Due to these limitations, the absence of controlled drinking and discrimination training from viable treatment options for alcoholics is not surprising.

3.2. BAC Estimation Training in Social Drinkers

Research examining the BAC estimation ability of alcoholic subjects frequently exhibited poor therapeutic results. In contrast, studies in samples of social drinkers produced more robust findings. Even prior to estimation training, nonalcoholic social drinkers monitored changes in BAC more efficiently than did alcoholics, suggesting greater baseline awareness of physiological and emotional variations corresponding to alterations in BAC (Lansky, Nathan, Ersner-Hershfield, et al., 1978). Bois and Vogel-Sprott (1974) investigated whether the ability of social drinkers to estimate BAC after training would ultimately facilitate avoidance of excessive alcohol doses. Social drinkers were trained to estimate BAC via association of internal sensations with accurate feedback, and ultimately learned to estimate BAC with minimal error when feedback was removed during testing. However, the design included repeated administration of the same dose, which may have confounded results by making accurate BAC estimates easier to obtain. Furthermore, subjects were provided BAC feedback at the start of the descending limb of the alcohol curve during all sessions. The investigators intended to provide a comparable reference point when BAC was falling, just as zero served as a starting reference point when BAC was rising. This feedback may have given too much external information to the subjects during testing and likely created a ceiling effect for BAC estimates. Using a similar design, Ogurzsoff and Vogel-Sprott (1976) assigned social drinkers to one of four groups based on frequency of drinking and usual amount of alcohol consumed per occasion. Despite vastly different drinking patterns, all subjects learned to accurately estimate BAC during testing in the absence of feedback.

Huber et al. (1976) trained three groups of social drinkers to estimate BAC via internal training, external training, or both, and all subjects received BAC feedback. At testing, the three groups did not differ in the ability to estimate BAC in the absence of feedback, and mean estimates were within .01% of actual BAC. This study unequivocally indicated that after sufficient training, social drinkers can estimate BAC without BAC feedback during testing. Although estimation ability clearly improved after training, the results did not confirm the superiority of one particular form of training. This study did not include a group that estimated BAC based on interoceptive cues alone, as the internal training group received external information including BAC feedback and administered dose during testing. Maisto and Adesso (1977) addressed these concerns by training nonalcoholic drinkers to discriminate BAC based on internal cues alone. Alcohol expectancy was manipulated in the first placebo-controlled study of BAC estimation training. This training technique was ultimately ineffective, however, as subjects were only accurate when expectancies concerning alcohol dose were correct.

Lipscomb and Nathan (1980) observed the effects of family history of alcoholism, drinking pattern, and behavioral tolerance to alcohol on the acquisition of BAC discrimination. Subjects listened to a relaxation tape, completed symptom checklists, and were instructed to associate internal cues with BAC feedback during training. Subjects with low tolerance were most effective in estimating BAC during testing, leading the authors to suggest that high tolerance in alcoholics may impede estimation accuracy. Menstrual phase has also been evaluated as a potential contributory factor to inaccurate evaluation of intoxication. Animal research has indicated that menstrual phase may affect drug discrimination (Green, Azarov, Szeliga, Purdy, & Grant, 1999). However, human studies of the role of menstrual phase in

BAC estimation accuracy have produced mixed results. Hay and colleagues (1984) measured the effect of menstrual cycle phase on BAC discrimination accuracy, but found no differences in discrimination ability. Subsequent research also failed to establish differential menstrual cycle effects on response to alcohol (Holdstock & de Wit, 2000).

A unique study that focused on the impact of direction of estimation errors characterized subjects after an ad libitum alcohol session as underestimators, overestimators, or mixed pattern estimators (Beirness, 1987). Underestimators consumed more alcohol *ad libitum*, rated their intoxication significantly lower relative to overestimators, and inaccurately judged themselves fit to drive. BAC underestimation is likely related to a heavy consumption history and increased tolerance to the effects of alcohol, making underestimators more at risk for driving under the influence (Bernosky-Smith et al., 2011). In the last published study of BAC estimation ability in social drinkers, external information was given about BAC-dose relationships, but no other training was provided (Martin et al., 1991). After consuming alcohol, subjects who reported lower intoxication ratings underestimated BAC significantly more than subjects who reported higher ratings. Subjects tended to underestimate BAC at the peak and descending limb of the blood alcohol curve, indicating misperception concerning the pace of alcohol elimination. Such erroneous expectancies about alcohol metabolism pose great danger when extended to judgments regarding driving ability after drinking.

3.2.1. Conclusions on BAC Estimation Training Studies in Social Drinkers—

Nonalcoholic subjects are capable of successfully gauging intoxication and impairment when properly trained. While initial studies provided dose feedback during testing, later research indicated that social drinkers, unlike alcoholics, could retain estimation accuracy during testing after removal of BAC feedback. The most efficacious training necessitates the inclusion of both internal and external training, and must include feedback about actual BAC (see Table 2). It is necessary for drinkers to pair external cues, such as quantity of alcohol, with self-perception of intoxication, and BAC feedback lends accurate reference points to such pairings. Additionally, alcohol tolerance appears to moderate unsound judgments about fitness to drive after drinking. Estimations appear to be most accurate when expectancies about alcohol dose are correct (Maisto & Adesso, 1977). When permitted, drinkers should be present for beverage preparation in both public drinking settings and private residences, avoiding beverages which may contain an unknown alcohol dose. Information concerning appropriate characterization of what constitutes a single alcohol drink would be effortless to disseminate, further facilitating increased precision of estimation. Such knowledge, if accompanied by education regarding effects of alcohol on reaction time at low doses, would allow drinkers to make informed decisions about legal driving ability, likely reducing alcohol-impaired driving below the legal limit as well.

3.3. Observational Studies in Naturalistic Drinking Settings

Investigations of BAC estimation ability have indicated that moderate drinkers can successfully discriminate BAC in laboratory settings. These studies have yielded popularity to observations of large samples of drinkers in their preferred drinking environment. Translation of BAC discrimination from the laboratory to natural drinking environments provides an important extension of prior literature by quantifying the long-term utility of training. Variables including beverage type, consumption rate, and total consumed dose are not manipulated, resulting in an accurate representation of typical public consumption. Location of consumption is a particularly influential variable, as social context and drinking setting can affect self-perception of behavior (Fromme & Dunn, 1992) and intoxication experience (Williams & Burroughs, 1995).

3.3.1. Bars—Public drinking establishments such as bars facilitate drink-counting as patrons must purchase each beverage. Despite clearly defined guidelines pertaining to what constitutes a single standardized drink (USDA and USDHHS, 2010), drinks in bars and other public drinking settings often contain significantly more alcohol than the typical standardized drink (Kerr et al., 2008). Perhaps the most evident characteristic that sets public venues apart from private ones is the increased likelihood of driving home while intoxicated. Party attendees may have the option of waiting until BAC has decreased prior to driving, while bar patrons must leave when the establishment closes. Consequently, intention to drive is an important outcome in investigations conducted with bar patrons.

Meier et al. (1984) compared the utility of Breathalyzer™ feedback to a chart displaying BAC as a function of body weight and total standard drinks in preventing impaired drinkers from driving. Control subjects received no such information. Eighty-three percent of individuals who were at or above the legal limit chose to drive home, despite receiving either type of feedback. This percentage may be elevated, however, as BAC in either the control or chart condition was not measured with a Breathalyzer™. Instead, BAC was estimated via analysis of dose consumed and time when drinking began. BAC determined in this manner has been extremely unreliable (Clapp et al., 2006, 2009; Kraus et al., 2005). Additionally, subjects in the Breathalyzer™ feedback group provided breath samples approximately five minutes following possible consumption. This short time duration may not have been sufficient for residual mouth alcohol to clear, likely resulting in overestimated readings (Spector, 1971). In a replication of this study in college-aged drinkers (Meier, Brigham, & Handel, 1987), estimated BAC derived from self-report information was compared to Breathalyzer™ readings. Subjects with low BACs were significantly more accurate in recalling consumption as compared to subjects with high BACs. The authors posited that this was a function of the inverse relationship between consumption and memory, although the effect was also likely related to decreased levels of tolerance in frequent drinkers. In a later study, the importance of accurate feedback was further highlighted. Johnson and colleagues (2008) found that self-reported impairment was correlated with BAC among subjects who received either no feedback or breath test unit feedback, but not categorical BAC feedback (e.g., 0.04-0.08%). Categorical feedback may override internal cues and create inaccurate alcohol expectancy effects.

Williams (1991) tested the hypothesis that in the absence of training, drinkers in a naturalistic setting would be poor estimators of BAC. Drinkers were sampled from two bars and asked to detail their general consumption patterns before estimating BAC. Subjects provided breath samples and speculated whether their BAC was in excess of the legal limit. Subjects with BACs below 0.05% or above 0.10% provided the most accurate self-evaluations. It may be more challenging to evaluate legal driving ability when BAC is near the legal limit of 0.08%. Many subjects in this study tended to overestimate BAC, and Williams posited that situational cues to intoxication may have enhanced caution regarding perceived driving ability in this sample.

3.3.2. Parties—Private drinking settings such as parties tend to provide fewer cues to intoxication as compared to public drinking establishments. Access to alcohol is less controlled, and drinkers may be less likely to track consumption as they are not required to purchase each drink. Additionally, the amount of alcohol per drink is generally unregulated at parties and other private settings, and many drinkers overestimate standard alcohol beverage volume (White et al., 2005; White, Kraus, McCracken, & Swartzwelder, 2003). Russ and colleagues (1986) examined BAC estimation ability and evaluation of legal intoxication by drinkers at a party. Individuals were approached upon entrance to the party and informed that their drinking would be monitored. Subjects often reported being impaired, but underestimated the number of drinks consumed. Thus usage of external cues,

such as counting drinks consumed, was not necessarily related to accurate estimation of BAC.

After hypothesizing that salience of cues to intoxication would vary as a function of setting, Williams and Burroughs (1995) determined differential effects of location on estimation ability. Drinkers consuming alcohol at a bar or fraternity party were asked to provide information about consumption patterns, estimate their BAC category, rate the salience of various cues to intoxication, and provide a breath sample. Relative to drinkers at a bar, party drinkers perceived situational cues as being more valuable for the evaluation of intoxication, supporting the hypothesis that drinkers use varying cues about impairment in different contexts. However, accuracy of estimation was not significantly different between the two locations.

3.3.3 College Campuses—Research involving college students often requires sampling subjects as they return home after drinking. Though it might be optimal to survey students at their preferred drinking venue, this is often difficult due to the prevalence of underage drinking at college bars or parties. Thombs et al. (2003) approached students as they returned to various residence halls in the evening. Subjects were asked to estimate BAC and provide a breath sample. Subjects tended to overestimate BAC when actual BAC was below 0.07%, while students exhibiting BACs in excess of 0.10% were inclined to underestimate BAC. The latter may begin to explain many decisions to drive in excess of the legal limit (Grant et al., 2012).

In many of these investigations, subjects estimate BAC, and are subsequently trained to improve estimation accuracy via administration of varying types of feedback. Johnson and Voas (2004) investigated the effects of providing potential drunk drivers with alternatives to breath test unit feedback. Students estimated BAC level, reported anticipated driving impairment, provided a breath sample, and self-administered a saliva-based BAC test that yielded a categorical BAC range. Saliva-based tests frequently placed subjects in a range below that of their actual BAC, and drinkers often reported feeling less intoxicated after testing. Fortunately, no differences were observed in perception of legal driving ability when pre- and post-test responses were compared.

3.3.4. Non-Specific Locations—Two important investigations did not specify a centralized location of consumption. The first included a sample of male soldiers who consumed alcohol at the end of a military course in Switzerland (Wicki et al., 2000). Consistent with results from Thombs and colleagues (2003), BAC was always overestimated, although the authors attributed this to the collection of estimates early in the elimination phase. Nearly three-quarters of drinkers who deemed themselves unfit to drive would have been considered below the legal limit for driving. This phenomenon may lend support to the notion that the United States legal limit should be reduced, as many social drinkers report experiencing intoxicating effects of alcohol at BACs below 0.08%.

The most recent observational estimation study examined the effect of access to BAC dose relationship charts, which provided the ability to estimate BAC, in a sample including drivers (Johnson and Clapp, 2011). Subjects were randomly assigned to varying feedback conditions, and a breath sample along with consumption information was collected upon return from drinking. Unfortunately, drinkers with access to BAC charts did not consume less than control subjects received no feedback. Drivers warned about risks associated with drinking and driving exhibited lower BAC than controls, but not when the warning was paired with a BAC chart. However, across conditions the mean BAC provided by drivers was 0.038%, which was significantly lower than the mean BAC of nondrivers (0.05%). As such, intention to drive plays an important role in decisions concerning consumption level.

Furthermore, as mean exit BAC did not exceed 0.05%, drinkers were rarely above the legal limit for driving. Replication of this research in subjects with higher BACs would extend the translational value of these results.

3.3.5. Conclusions on Observational Studies—An asset of observational studies is the ability to monitor beverages consumed *ad libitum* (Thombs et al., 2003). Meticulous observation by researchers in naturalistic settings can combat negative facets of self-report data such as poor recall or lack of knowledge of what constitutes one standard alcohol drink. Unlike doses administered in many laboratory studies, doses of alcohol in public and private drinking establishments are not corrected for body weight or gender. Although there is utility in controlling for peak breath alcohol in the laboratory, the amount of alcohol in beverages is fairly consistent within public venues. Due to differences in body mass index, one drink may result in distinct BACs between drinkers. Thus, it is important for drinkers to understand their own impairment at various BAC levels and this becomes even more crucial when paired with intention to drive. Furthermore, alcohol content is often unregulated at private parties or informal settings (White et al., 2005). Naturalistic studies provide increased validity by observing consumption that is unhindered by the confines of a dose controlled for sex and body weight. Observational studies also frequently include individuals who might be below the legal drinking age. These subjects are generally excluded from laboratory studies that require alcohol administration, yet are worthy of study due to the wide prevalence of underage drinking (Aldworth, 2009). Perhaps the strongest advantage of observational research is the ability to present conclusions drawn from a substantial sample size (see Table 3), strengthening the translational utility of the data.

4. Discussion

Although BAC estimation training was initially limited to behavioral therapy for alcoholics, it has become an educational intervention for social drinkers, and is now a component of drunk-driving reduction programs. Whether such training elicits subsequent behavior change, however, is still under investigation. Observational studies have presented mixed results regarding the effects of providing drinkers with tools to evaluate intoxication level. Several factors influence estimation ability and motivation to make cautious decisions in naturalistic settings, including presence and type of feedback, intention to drive, and drinking setting. However, no clear picture as to the combined role of these factors has yet emerged.

Tolerance to the effects of alcohol greatly impacts the subjective experience of intoxication, and ultimately the ability to estimate BAC. Symptoms of intoxication may have less salience for individuals with higher tolerance, and thus would be more difficult to associate with specific BACs (Nathan & Lipscomb, 1979). As indicated from controlled drinking studies, alcoholic drinkers have reached a level of intoxication sufficient to impede accurate pairing of interoceptive cues and blood alcohol level. However, the point at which tolerance begins to negatively impact the ability to evaluate impairment is unknown. Although they are not alcoholics, problematic binge drinkers may have reached a level of tolerance sufficient to impede specific cue-BAC connections, rendering accurate judgments about legal driving ability difficult. Drinkers who report frequent binge drinking often experience decreased sedation after alcohol consumption compared to nonbinge drinkers (Marczinski, Harrison, & Fillmore, 2008). This effect may have led participants to believe they had returned to sobriety before BAC sufficiently decreased. Binge drinkers have displayed an inability to recognize absence of tolerance to the psychomotor effects of alcohol (Bernosky-Smith et al., 2011), and this may impede any cautionary effects of estimation training. Consequently, BAC estimation training may not be therapeutically effective for frequent binge drinkers.

In addition to tolerance level, sex may play an important role in estimation ability. Twelve of the nineteen reviewed laboratory studies failed to include female participants (refer to Tables 1 and 2). Males and females display distinct variations in the metabolism of alcohol and associated pharmacokinetics (Baraona et al., 2001). Under the same alcohol dose, females achieve higher peak BACs as compared to males, despite rapid rates of alcohol elimination (Jones & Jones, 1976; Niaura, Nathan, Frankenstein, Shapiro, & Brick, 1987). Differences in peak BAC level may result in varying subjective and biphasic effects of alcohol, factors strongly related to internal estimation training techniques. Consequently, metabolic variations between male and female drinkers may impact estimation ability. In addition to the underrepresentation of female participants in published BAC estimation and controlled drinking research, studies concerning sex differences in estimation ability are virtually absent from the current literature. Thus, the influence of sex on BrAC estimation ability may be a valuable component of future investigations.

Perception of BAC is likely mediated by alcohol metabolism which in turn is affected by sex and several other variables, including body weight, and food intake (Barquín et al., 2008). These and other characteristics capable of influencing estimation ability on an individual basis cannot always be incorporated into a portable card or warning statement. Many drinkers remain unaware of the cognitive, motor, and psychological effects of alcohol at BAC levels below the legal limit. Ultimately, when the law states that 0.08% is the legal limit for driving, the assumption that lower levels are safe will follow. Education regarding negative consequences and outcomes of driving after even moderate consumption may help to correct misperceptions concerning drinking and driving. Many drinkers experience significant subjective effects of alcohol below 0.08%. As these deleterious alcohol effects may affect the decision to drive, such findings should be considered when developing appropriate legal limit laws.

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Highlights

- Reviews history of training of blood alcohol concentration estimation.
- Alcoholics are unable to make accurate self-estimates of blood alcohol concentration.
- Moderate drinkers can be trained to self-estimate blood alcohol concentration.
- Naturalistic self-assessment studies derive validity from typical use patterns.
- Breath alcohol estimation training imparts individualized perception of impairment.

Table 1

Summary of Controlled Drinking Study Characteristics

Authors, Year	N (% female)	Population	Control Group?	Minimum Subjects per Condition	Training	% Attrition
Lovibond & Caddy, 1970	44 (20)	Alcoholics	Yes	13	AC, AF, DT, ET, IT	25
Silverstein et al., 1974	4 (0)	Alcoholics	No	4	AF, DT, ET, IT	50
Vogler et al., 1975	59 (not reported)	Alcoholics	Yes	19	AF, AC, BC, DT, ET, IT, VF	29
Caddy & Lovibond, 1976	60 (18)	Alcoholics	No	20	AC, AF, DT, ET, IT	27
Strickler et al., 1976	3 (0)	Problem Drinkers	No	3	AF, DT, ET, IT	0
Vogler et al., 1977	132 (not reported)	Problem Drinkers	Yes	17	AC, AF, BC, DT, ET, IT, VF	39
Miller, 1978	65 (not reported)	Problem Drinkers	Yes	8	AC, DT, ET, IT	17
Lansky et al., 1978	8 (0)	Alcoholics	No	4	AF, ET, IT	0
Ludwig et al., 1978	60 (0)	Alcoholics and Social Drinkers	Yes	20	AF, DT, ET, IT	0
Shapiro et al., 1980	8 (0)	Alcoholics	No	4	AF, DT, ET, IT	13

^aTraining Abbreviations: AC: Aversive Conditioning, AF: Accurate Feedback, BC: Behavioral Counseling, DT: Discrimination Training, ET: External Training, IT: Internal Training, VF: Videotaped Feedback

Table 2

Summary of Studies Focused on Moderate Drinkers

Authors, Year	N (% female)	# Drinks/Total Time	Total Dose: g/70kg	Minimum Subjects per Condition	Training
Bois & Vogel-Sprott, 1974	9 (0)	4 Drinks/80 min	44	9	AF, DT, ET, IT
Ogurzsoff & Vogel-Sprott, 1976	20 (0)	4 Drinks/80 min	44	5	AF, ET, IT
Huber et al., 1976	36 (0)	6 Drinks/180 min	65*	6	AF, ET, IT
Maisto & Adesso, 1977	72 (0)	3 Drinks/ 60 min	Peak BAC = 0.08%**	6	AF, ET, IT
Lansky et al., 1978	56 (0)	6 Drinks/180 min	65*	20	NT
Lipscomb & Nathan, 1980	24 (0)	6 Drinks/240 min	64	6	AF, ET, IT, RT
Hay et al., 1984	20 (100)	6 Drinks/240 min	66*	9	NT
Beirness, 1987	72 (47)	Ad Libitum/Not Reported	N/A	14	NT
Martin et al., 1991	39 (0)	2 Drinks/10 min	41	19	ET

^aTraining Abbreviations: AF: Accurate Feedback, DT: Discrimination Training, ET: External Training, IT: Internal Training, NT: No Training, RT: Relaxation Tape

* Same dose administered to all subjects

** Specific dose information not provided

Table 3

Summary of Naturalistic Observational Study Characteristics

Authors, Year	N (% female)	Sampling Location	Immediate Feedback?
Meier et al., 1984	72 (not reported)	Bar	Yes
Russ et al., 1986	93 (not reported)	Party	Yes
Meier et al., 1987	36 (28)	Bar	Yes
Williams, 1991	99 (20)	Bar	Yes
Williams & Burroughs, 1995	92 (32)	Bar	Not Reported
Wicki et al., 2000	45 (0)	Not Reported	Not Reported
Thombs et al., 2003	1020 (44)	College Campus	No
Johnson & Voas, 2004	129 (16)	College Campus	Yes
Johnson et al., 2008	959 (27)	Bars and Restaurants	Yes
Johnson & Clapp, 2011	1215 (48)	Mexico-United States Border	Yes