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Comparison of transdermal alcohol concentration and self-reported alcohol consumption in people with alcohol dependence attending community alcohol treatment services

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ABSTRACT

Aim: We aimed to assess the accuracy and wearability of a transdermal alcohol sensor (TAS) (BACtrack Skyn) with people currently receiving treatment at alcohol services.
Method: A mixed methods observational study involving three NHS alcohol services in south London was conducted. All participants (7=male, 9=female) wore a TAS for 1 week and met with the researcher every other weekday to complete the TAS data download and a TimeLine Follow Back (TLFB). At the end of the week, a post-wear survey was completed. Transdermal Alcohol Concentration (TAC) from the TAS was compared to the TLFB. Post-wear survey responses, attendance voucher incentives and descriptive TAS data (removals, missing and skin temperature data) were analysed. We investigated different drinking event thresholds changing the criteria of TAC level and length of time TAC was increased and analysed each drinking threshold sensitivity, specificity, positive and negative predicative values, and percentage accuracy classification.
Results: The TAS recorded the number of alcohol-drinking days with a high degree of accuracy compared to the TLFB as gold-standard. However, of the participation time of the 16 participants, 14.5% of the TAS data was missing in output and 16.4% of the recorded data suggests the TAS was not currently being worn. Of the data recorded, in line with the drinking event threshold of >15 ug/l TAC, >15 minutes, we found that sensitivity = 93%, specificity = 84% and a Pearson correlation of r(16) =.926, p = <.001, BCa 95% CI [.855 −.981]. The threshold with the highest accuracy was TAC>15 ug/l, >60 minutes which classified alcohol events with 90% accuracy, AUC =.910, sensitivity = 90%, specificity = 96%. The post-wear survey reported that most participants found it comfortable and that wearing it did not interfere with daily activities. Six participants reported side effects, including itching and a rash, but these would not deter them from wearing it again with all six reporting they would wear the TAS again and for longer than one week.
Conclusions: The TAS did not capture every drinking event that was self-reported but maintained a high correlation. There were instances of missing TAS data and TAS removals. Overall, our findings would support the acceptability and feasibility of TAS as a tool that could be used in clinical settings for objective alcohol monitoring with patients being responsible for the TAS.

1. Introduction

Transdermal alcohol sensors (TAS) are devices that can be worn on a wrist or ankle with a non-invasive sensor against the skin. This sensor can determine alcohol consumption from the sweat vapours of the skin at regular intervals for as long as the device is worn, and the battery charged. Global research has investigated TAS use with different populations, including, healthy adults (Ariss et al., 2022; Davidson et al.,

Abbreviations: AUC, Area under the curve; .AUD, Alcohol use dependence; .BAC, Blood alcohol concentration; .BrAC, Breath alcohol concentration; .CM, Contingency management; .EMA, Ecological momentary assessment; .NPV, Negative predictive value; .PAC, Percentage accuracy in classification; .PPV, Positive predictive value; .ROC, Receiver operating characteristics; .SCRAM, Secure continuous remote alcohol monitor; .TAC, Transdermal alcohol concentration; .TAS, Transdermal alcohol sensor; .TLFB, Timeline Follow Back; .UK, United Kingdom; .US, United States.

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1997; Fairbairn et al., 2018, 2019; Fairbairn and Kang, 2019), adults diagnosed with alcohol use dependence (AUD) (Alessi et al., 2017, 2019; Sakai et al., 2006; Swift et al., 1992), adults with an alcohol-related offence (Goodall et al., 2016), and adults with HIV (Richards et al., 2022; Villalba et al., 2020). In addition, previous research has investigated TAS wear for different lengths of time, some occurring within a 24-hour period (Ayala et al., 2009; Brobbin et al., 2023; Fairbairn and Kang, 2019; Wang et al., 2019), but some studies involved TAS wear over a few days to a week or two (Barnett et al., 2017; Croff et al., 2020; Dougherty et al., 2015; Luczak et al., 2015; Norman et al., 2020; Rash et al., 2019), with the longest being 16 weeks (Dougherty et al., 2015). Many of these studies have been conducted with healthy adult volunteers in a laboratory with earlier, more established TAS brands, such as SCRAM and WrisTAS (Barnett, 2015; Dougherty et al., 2012, 2015; Fairbairn et al., 2019, 2020; Fairbairn and Kang, 2019; Greenfield et al., 2014; Hill-Kapturczak et al., 2014; Karns-Wright et al., 2017; Roache et al., 2015; Swift et al., 1992; van Egmond et al., 2020). The BACtrack Skyn is a relatively new brand of TAS, with a smaller number of published findings compared to SCRAM and WrisTAS. A difference between Skyn and these older TAS brands is the ability to be paired to a smartphone application to display real-time data. This feature of Skyn would allow real-time monitoring which could be used by clinicians to employ real-time personalised treatment interventions. Of these studies using the BACtrack Skyn, three used the prototype version (Fairbairn et al., 2020; Fairbairn and Kang, 2019; Wang et al., 2019) and five used the newer generation model (Ariss et al., 2022; Ash et al., 2022; Richards et al., 2022; Rosenberg et al., 2021; Wang et al., 2021).

Previous publications using Skyn had a range of study designs (Ariss et al., 2022; Ash et al., 2022; Fairbairn et al., 2020; Fairbairn and Kang, 2019; Richards et al., 2022; Rosenberg et al., 2021; Wang et al., 2019, 2021). Two used Skyn and compared it to ecological momentary assessment (EMA) over two weeks (Richards et al., 2022) or 28 days (Rosenberg et al., 2021). Another two compared Skyn to breath alcohol concentration (BrAC) in a laboratory setting (Brobbin et al., 2023; Fairbairn and Kang, 2019; Wang et al., 2021). Five compared Skyn to another brand of TAS ranging from 1 to 28 days of wear (Ash et al., 2022; Fairbairn and Kang, 2019; Rosenberg et al., 2021; Wang et al., 2019, 2021). One used previously collected Skyn data and machine learning models to estimate BrAC from TAC (Ariss et al., 2022). While all studies recruited adults with varying criteria for alcohol consumption, none included patients with a clinically diagnosed alcohol use disorder, and one had criteria excluding current alcohol use disorder or those with alcohol withdrawal symptoms (Ariss et al., 2022).

TAS has the potential to be used in a variety of settings, including clinical alcohol treatment. They could be worn by those accessing alcohol services for continuous, objective, and non-invasive alcohol monitoring over several weeks. Alcohol services currently use tools, such as breathalysers, which can only detect alcohol use from the past few hours, or self-report, which can be subject to recall bias (Saunders et al., 1993; Sobell and Sobell, 1992). However, TAS can measure alcohol consumption continuously (every minute), identifying when alcohol is consumed and how much, allowing it to detect any peaks in use while the device is worn. At present, TAS has a slight time delay between transdermal alcohol concentration (TAC) and breathalyser measurements that must be accounted for (Brobbin, Deluca, Coulton, et al., 2023; Fairbairn and Kang, 2019; Rosenberg et al., 2021; Sakai et al., 2006; Wang et al., 2019). However, recent research shows advancements in this technology and a reduction in time to peak TAC (Ariss et al., 2022; Fairbairn et al., 2019; Marques and McKnight, 2009; Norman et al., 2020; Rosenberg et al., 2021). For these reasons, TAS could have utility in the context of alcohol treatment and a reliable measure that could facilitate the implementation of contingency management (CM) for this population.

Much of the previous TAS research has included healthy volunteers, and now research has begun to explore the accuracy of TAS in various settings, including naturalistic settings and AUD adults (Alessi et al., 2017, 2019; Barnett et al., 2011, 2017; Sakai et al., 2006; Swift et al., 1992). Most of this research has been conducted using SCRAM but results were encouraging for TAS feasibility in clinical community settings and the use of TAS to deliver CM to reduce alcohol consumption. However, comments were made on the size, discomfort, and limited water resistance of SCRAM by wearers (Alessi et al., 2017, 2019; Barnett et al., 2011, 2017). Now that there are smaller, wrist-worn TAS, such as the BACtrack Skyn, some of these wearer burdens may be able to be reduced and this could have a meaningful impact on TAS engagement, acceptability, and feasibility. Previous research has established the ability to distinguish alcohol-dependent vs non-alcohol-dependent use with SCRAM (Sakai et al., 2006) and shown to characterize alcohol consumption measured with SCRAM among AUD patients (Alessi et al., 2019), but it is important to investigate this with newer TAS particularly as many TAS brands are currently targeted for general use rather than clinical use. Therefore, we decided based on discussion with service staff (Brobbin et al., 2024) that a week would allow sufficient data collection of continuous alcohol consumption of large quantities from an AUD population.

Our study aimed to assess the accuracy of the BACtrack Skyn with people receiving alcohol treatment whilst wearing the device for one week, compared to the current gold standard of Timeline Follow-Back (TLFB) (Sobell and Sobell, 1992) self-reported alcohol consumption. We also evaluated the use of incentives (vouchers) for meeting attendance compliance and device return.

2. Materials and methods

2.1. Participants

Recruitment occurred between July and October 2022 among those attending three alcohol treatment services in south London, UK. These were free services provided by the NHS, delivered in the community (i.e. not residential) offering a range of drug and alcohol treatments.

Participants were referred by service staff and by the researcher attending patient groups to discuss the study. The inclusion criteria were: 1) receiving treatment for an alcohol use disorder, 2) aged 18 years or more, 3) speak English competently enough to have a conversation without a translator, 4) able to meet throughout the study period 5) able to provide informed consent. Those interested were given a Participant Information Sheet by the researcher or a service staff member. The study details, and what was expected from them were also explained by the researcher. They were then given at least 24 hours to consider this information before the researcher contacted them again to ask if they were willing and interested in participating. If they were, the researcher then arranged to meet for their enrolment and first research meeting.

The study inclusion criteria were intentionally kept broad, enabling individuals receiving any treatment for an alcohol use disorder (provided they met the other criteria) to participate. In this study, we wanted to explore TAS use at different stages of alcohol treatment as staff posit different uses for TAS at different points of treatment (Brobbin et al., 2023, in press). This includes when individuals first present at an alcohol service, during detox, and post detox. There was no exclusion criteria based on the amount of alcohol currently being consumed (i.e. abstinence was not required).

2.2. Procedure

Each participant met with the researcher four times over seven days. At the first meeting, the participant was trained in using the TAS (how to wear it and how to check it was turned on and had power). They were provided with written information and photographs of this to take away with them. The following three meetings occurred every other day (excluding weekends). Meetings two and three were for data download and completing the Timeline Follow Back (TLFB) (Sobell and Sobell,

1992). In the final meeting, a post-wear survey and a semi-structured interview were completed. All participants were informed that participation and wearing the TAS was voluntary however they were asked to always wear it, including while asleep, with removals only for water activities (shower, bathing, swimming) as it is not waterproof. However, if they decided to remove it or stop wearing it completely, they were informed there was no consequence to their participation, treatment, or care. The reason for this research meeting schedule was to ensure that no data was overwritten on the BACtrack Skyn, which currently can hold data for approximately 72 hours. A day was measured as occurring from 00:00 a.m. – 23:59 p.m. in the TAS output.

Participants completed a TLFB with the researcher at every meeting, so they only had to recall alcohol consumption for the previous two to three days (Merrill et al., 2020). The TLFB is a calendar-based measure to record self-reported substance use and days were recorded as occurring from 00:00 a.m. – 23:59 p.m. Participants were provided with a £10 shopping voucher for the first meeting and a £20 shopping voucher for their final meeting. Travel expenses were reimbursed. The study was approved by the Surrey Research Ethics Committee (ref: 22/LO/0426) and registered on Open Science Framework.

2.3. Measures

The primary outcome measures for alcohol consumption were the TLFB and TAS. The TLFB was self-reported (Sobell and Sobell, 1992) and was used to determine alcohol-drinking days and how many units were consumed (In the UK: 8 g or 10 ml of pure ethanol = 1 unit). The TAS used was the BACtrack Skyn. It was worn on the participant's preferred wrist and continuously measured TAC and skin temperature (Celsius). Output was reported at 1-minute intervals. A day with an alcohol event, that met the TAC criteria (see below), was recorded as an alcohol-drinking day.

2.3.1. Secondary outcomes included

1) Compliance, engagement, and reasons for incomplete data. Compliance was defined as participants wearing the Skyn correctly as instructed (not including during water activities). Engagement was defined as the number of meetings the participants attended. Reasons for incomplete data were noted, it could be due to participant illness or non-attendance meaning that the Skyn data would be overwritten (as it can only store 72 hours), or it could be due to device error.
2) Frequency of confirmed tampers, adjustments, device replacements and removals. We recorded the number of confirmed tampers (defined as the participant doing something to stop the Skyn recording), the number of times that participants contacted the researcher for placement adjustment of the Skyn and the number of times the Skyn broke, requiring their Skyn to be replaced. We measured a Skyn removal as a period lasting longer than two minutes, where the skin temperature was measured as below 30 degrees Celsius.
3) Number of Skyn devices returned intact.
4) Completion of the post-wear survey. Participants also completed an interview on their TAS experience as part of a qualitative component attached to the study (Brobbin et al., (2023)b, under review, (Brobbin et al., 2023).

2.4. Data handling/transformation

There is currently no guidance from BACtrack to determine drinking event criteria. Courtney et al., describe their procedure for processing Skyn output to identify drinking episodes and we used these guidelines when processing participant data (Courtney et al., 2022). We replaced any negative values recorded to zero in the data output. Missing data were classified as any minutes not reported. Removed data were those with a temperature below 30^0 C longer than two minutes.

An alcohol event was based on TAC greater than a specific value (ug/L) for more than a set number of minutes. We started our analysis using a criterion of TAC>15 ug/l for 15 minutes or longer based on our previous laboratory-based study (Brobbin et al., 2023). We also explored other criteria thresholds.

2.5. Analysis

Descriptive socio-demographic and TAS data were reported (removals and missing output data). Data were assessed manually to identify alcohol exposure. The analysis focused on the sensitivity, specificity, positive predictive value, and negative predictive value of TAC compared to TLFB as the gold standard. The correlation between drinking and abstinent days were assessed using Spearman Rank Correlation coefficient. The post-wear survey responses, engagement, device return, and incentive use were reported. We generated Receiver Operating Characteristics (ROC) curves to compare different alcohol-drinking day criteria. The area under the curve (AUC) is considered a measure of the predictive power of each criteria threshold. Sensitivity in detecting alcohol events and specificity in classifying an alcohol-drinking day vs. a non-alcohol drinking day were assessed. Statistical analyses were conducted using SPSS v28.

3. Results

3.1. Baseline characteristics

Nineteen individuals were approached. Three declined to participate as they did not want to wear the TAS (n=1), had concerns about tracking (n=1), or were unable to meet the researcher (n=1). A total of 16 enrolled and completed the study. Fifteen out of 16 participants were either retired or currently unemployed. One participant opted out of the study two days earlier than planned as they did not wish to wear the TAS any longer but still completed the TLFB, post-wear survey and interview. All participants completed all measures and returned devices intact. All sixteen participants who enrolled were included in the analysis. Table 1

3.2. Descriptive TAS data

Participants wore the TAS for a cumulative total of 157,341 minutes and removed the TAS for 25,856 minutes (16.4% of study participation). There were 22,745 minutes (14.5%) of missing data. Therefore, just under one-third (48,601, 30.9%) of the total time, Skyn was not recording TAC. Some removals were expected, especially when showering as Skyn is not waterproof. One participant reported to the researcher that their TAS had stopped working and so an extra meeting was arranged to provide a new TAS. No other participants contacted the researcher to request additional meetings. No fit adjustments were required. On 57 out of 126 days, the TAS was either removed or did not provide data for a continuous one-hour period. Additionally, on 45 out of 126 days, the TAS was either removed or did not provide data for a continuous five-hour period.

Table 1
Participant characteristics.

Characteristics Mean (SD)	Male (n=7)	Female (n=9)	Combined (N=16)	Sex difference
Age	57.6 (11.93)	50.9 (14.29)	53.8 (13.32)	p=.135
BMI	28.0 (7.32)	26.4 (5.77)	27.1 (6.35)	p=.436
Height (cm)	170 (6.58)	163.5 (5.50)	166.5 (6.71)	p=.695
Weight (kg)	81.1 (22.75)	70.4 (14.41)	75.4 (18.88)	p=.159
Ethnicity| Caucasian n	7	9	16	

Significant p<0.05. One participant was not weighed, nor height measured, on their request.

3.3. Skyn vs TLFB

Both TLFB and Skyn reported 70 days as alcohol-drinking days out of the total study days participants wore the devices. However, these 70 days were not an exact match. Some days are reported as drinking days by self-report and vice versa. The TAS did not detect alcohol consumption on eight days that were self-reported by participants (see Table 2). For four of these days, a high percentage of the day had missing data (device error). For two of the days, TAS data suggests the device has been removed or worn too loosely to report accurately (temperature sensor). For the last two days, it appeared as if the device was being worn and data were recorded but the TAC output does not meet our alcohol-drinking event criteria (TAC>15 ug/l >15 minutes).

In addition, eight days were recorded as drinking days by the TAS but not by TLFB. This could be due to the participant using a hand sanitiser or alcohol-containing product very close to the sensor on their wrist which could have led to the increase in TAC, or the participant misreporting alcohol consumption. To account for this, we considered a criterion of TAC>15 ug/l >60 minutes. Using this criterion, the number of TAS-reported drinking days that are not self-reported was reduced from eight to two. In Fig. 1, below we provide a visual representation of whether TLFB reported an alcohol-drinking day or not according to TAC data at two thresholds for each participant.

We calculated the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and percentage accuracy in classification (PAC) for different drinking event thresholds (Table 3).

A Spearman correlation found a significant relationship between self-reported and Skyn measured alcohol drinking days, $r(16) = .907$, $p = <.001$, BCa 95% CI [.754 −.967]. A Spearman correlation between the number of standard alcohol units self-reported and the highest TAC value measured, and another with the average TAC value were both found to be significant, $r_s(16) = .687$, $p = .003$ BCa 95% CI [.184 −.921], $r_s(16) = .878$, $p = <.001$ BCa 95% CI [.633 −.952], respectively.

Fig. 2 displays the data for TAC and the skin temperature of all participants who wore the TAS for the entire study period. There are participants whose TAC (blue line), peaks on separate occasions, suggesting multiple alcohol events, for example, Participant 3. While other participant data suggests more frequent alcohol consumption, for example, Participant 6. The orange lines depict skin temperature recorded, Participant 14 shows regular nightly removals (seven nights of the study period). Participant 6 has two distinct removals where both the temperature and TAC reduce and then increase when replaced on the skin.ROC analyses were conducted for the peak TAC recorded each day for each participant against their TLFB as binary variables for an alcohol-drinking day or not. A further ROC analysis was conducted for the average TAC recorded each day compared to TFLB. The ROC curve comparing peak TAC (criteria: TAC>15 ug/l >15 minutes) to TLFB, had an AUC of =.875 (OR = 46.500, 95% CI [16.273 – 132.872]) and criteria: TAC>15 ug/l >60 minutes had an AUC of =.910 (OR = 162.000, 95% CI [33.972 – 772.520]), presented in Fig. 3a. The ROC curve comparing average daily TAC (criterion: TAC>15 ug/l >45 minutes, TAC>25 ug/l >45 minutes) to TLFB, (Fig. 3a and b), also had the highest AUC of =.910 (OR = 162.00, 95% CI [33.972 – 772.520]). These results suggest that both criteria presented can predict an alcohol-drinking day with good reliability but that a slightly higher TAC or length of alcohol event deliver a higher level of agreement with TLFB than the TAC>15 ug/l >15 minutes criteria.

Fig. 3a-b. ROC curves.

Table 2
Alcohol-drinking days and non-alcohol drinking days reported by TLFB and TAS.

	Total					
	Alcohol days	Alcohol days in agreement	Non-alcohol days in agreement	Days reported by TAS as alcohol-day but not by TLFB	Days reported by TLFB as alcohol-day but not by TAS (reasons for TAS not reporting an alcohol day)	
TLFB	70	62	48	8	8	(Missing data = 4 days Device removal = 2 days
TAS	70					Does not reach TAC criteria = 2 days)

4. Secondary measures

The other measures collected included compliance, engagement, and reasons for incomplete TAS data. Compliance was defined as wearing the TAS correctly. All participants were trained on how to wear the Skyn in the first meeting and we found that all participants were wearing the Skyn correctly at research meetings. Participants were asked to wear it throughout the day and night only removing it for water activities (bath, shower, swimming) or if they did not want to continue wearing it. A total of 14/16 reported wearing it at night, two made the researcher aware that they were unable to sleep with it and so removed it each night. There was also one participant who reported removing it for one day to nap. Otherwise, no other participants reported instances of non-compliance. Participant engagement was defined by research visit attendance, all participants attended all meetings. Therefore, reasons for incomplete data are unlikely to be due to the Skyn storage and data overwriting but either Application or device error.

Tampers were defined as the participant purposefully turning off or interfering with the Skyn to avoid alcohol consumption monitoring. As there was no consequence to alcohol consumption or removal, and the Skyn is removable by the wearer, we did not expect tampers, and none were reported by participants or detected by the research team. There was also no additional contact from the participants after the first meeting to ask about Skyn adjustments. One participant did need to contact to replace their Skyn due to device error. All Skyn were returned intact to the research team by each participant. Removals are reported in above descriptive TAS data. One participant did end their participation on day six rather than day eight due to not feeling comfortable wearing the Skyn any longer, stating it reminded them of their need for alcohol treatment.

4.1. Post-wear survey

The post-wear survey average response scores are included in Supplementary Information. When asked about physical comfort, most rated it as being quite to very comfortable (average score: 8.31 out of 10). Social comfort was rated favourably, most participants found it 'neither was, nor was not socially uncomfortable'. When asked about how often they noticed the Skyn on their wrist, only two out of the sixteen stated they never noticed it. Most noticed it a few times a day, and 15 reported that it did not interfere with general activity (such as exercise, mood, work, sleep, life, ability to concentrate or clothing choices).

Six participants reported side effects from wearing the TAS. When rated on a scale of 1 – 10, (where 1 = not noticeable, 10 = unbearable), the highest scores were for itching (=6), sweating (=7) and irritation (=6). One participant also reported a bruise on their wrist (=5) and two reported a rash (3 and 6).

Almost all (15/16) would wear the device again, ranging from two weeks to indefinitely, including all six participants who reported side effects. The participant who would not be willing to wear it again was the participant who chose to end participation early. The participant

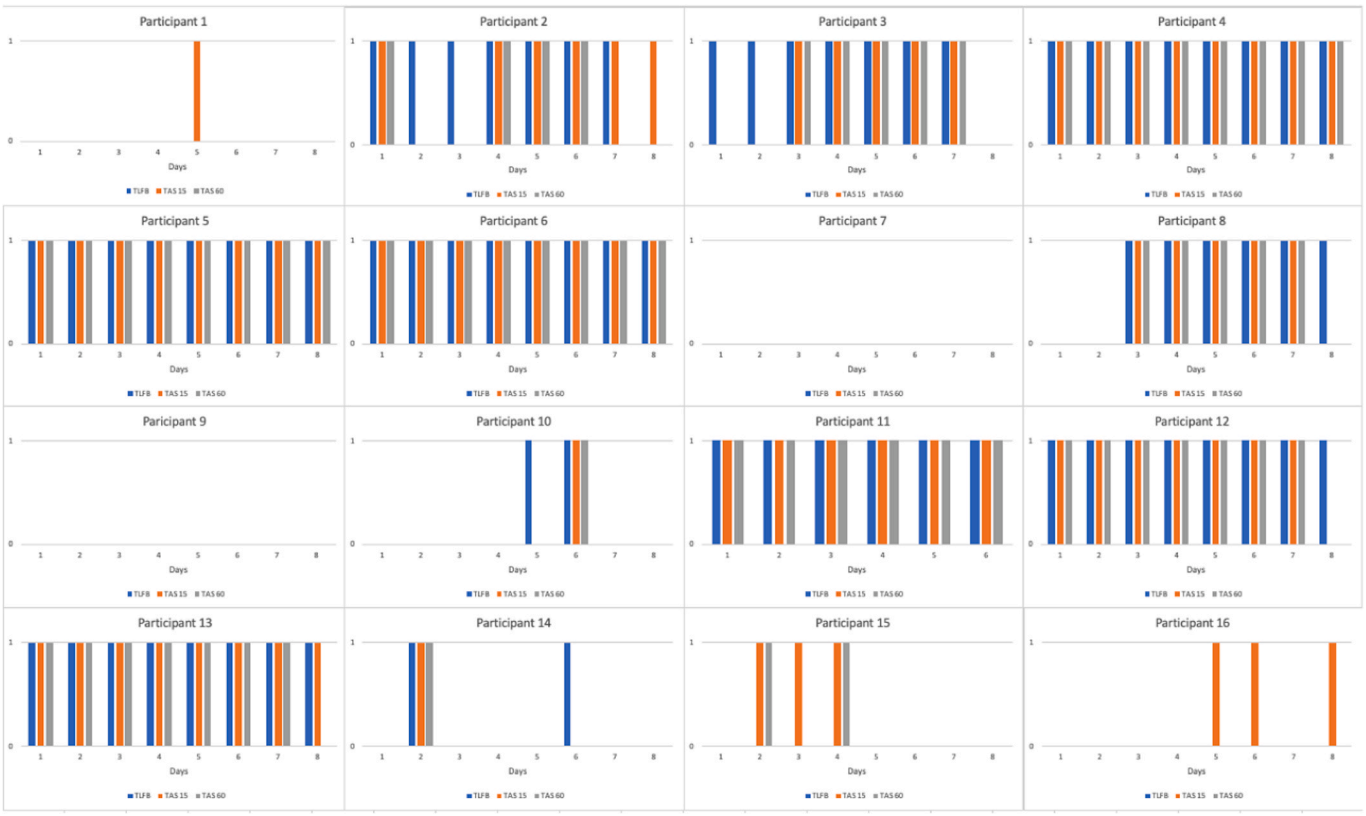

Fig. 1. Participant self-reported and device-reported drinking days. Visual presentation of participants TAS detected and self-report drinking days. 1 = Drinking Day, 0 = Non-drinking day.

explained this was due to what the TAS represented to them.

Statements asking about changing their clothes choice, wanting to remove the TAS and not liking the regular download visits, all had an average score of 0.25 (on a scale of 0–4 where 0= "Not true" and 4 = "Very true"). All participants rated regular visits as "not at all difficult to attend", although some stated that this was because they were not currently in employment.

5. Discussion

Our aim was to assess the accuracy of Skyn with people attending alcohol treatment services and wearing it for one week. Our findings support TAS monitoring alcohol-drinking days with high sensitivity and specificity compared to self-reported alcohol consumption. The accuracy achieved by the BACtrack Skyn within a clinical population, based on these TAC criteria thresholds is similar to, or higher, than correlations, sensitivity and specificity reported in earlier studies using SCRAM and WrisTAS comparing TAC to self-report or BrAC on TAC sensor accuracy standards with non-clinical volunteers (Bond et al., 2014; Dougherty et al., 2012; Simons et al., 2015). Even when considering a threshold that would meet 100% specificity, sensitivity levels are still reasonably high (80% sensitivity, criteria: TAC>15 ug/l >90 minutes). Considering our results compared to previous work published on any TAS, this study found higher reported sensitivity and specificity than earlier studies published using WrisTAS (Bond et al., 2014; Croff et al., 2020; Marques and McKnight, 2009; Simons et al., 2015), which could suggest this BACtrack Skyn model shows improvements to earlier TAS and prototypes. However, studies using SCRAM have reported higher sensitivity for estimating the number of drinks consumed (Dougherty et al., 2012). There are currently no recommendations by the manufacturer to determine an alcohol event with BACtrack Skyn, unlike for SCRAM (Barnett et al., 2011, 2014). Other studies could be using different protocols to determine alcohol events and therefore interpret Skyn data differently, making it difficult to directly equate Skyn results across research. This study included regular meetings between the researcher and the participant. However, it should be noted that no participant required additional training after the first research meeting and no participant asked the researcher to readjust their TAS.

Reasons for Skyn and TLFB alcohol-drinking days not matching exactly may include TAC missing data, removal, events not captured by the criteria, misreported consumption, or use of an alcohol-containing product. Currently, there are no solutions known to the research team to reduce missing data, and TAS wear was voluntary, with removal required when bathing. Previous studies also report TAS missing data and removals (Ariss et al., 2022; Ash et al., 2022; Brobbin et al., 2022; Courtney et al., 2022) and a recent publication also discusses the various challenges of BACtrack Skyn data collection and analysis (Gunn et al., 2023). While this was published after our data collection, we were able to retrospectively check that we were making many of their recommendations for best practices when using Skyn. Like Gunn et al., (Gunn et al., 2023) we found the Skyn data to be quite noisy and decided to use an automated approach to identify and exclude environmental alcohol exposure. They suggested frequent observations, repetitive demonstrations and providing materials to help participants troubleshoot TAS use. Despite not having these recommendations while preparing our study, our design included regular visits and a training leaflet with photographs of common troubleshooting. We found this helped participants and no other training was required. One recommendation they had which we did not was asking participants to note removal times. In hindsight, this would have been useful to match with our automated removal TAC output, however, we did not want to add this additional burden to participants in this study.

Although our findings suggest a high level of accuracy for Skyn objectively monitoring alcohol consumption, the implications of a small number of inconsistently reported events between TAS and TLFB also must be considered. A suggested use of TAS is to provide an objective,

Table 3
Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and the percentage accuracy in classification (PAC).

Criteria	Sensitivity	Specificity	+ Predictive value	- Predictive value	PAC
TAC >15 ug/l 15 minutes	86%	86%	.86	.86	.87
TAC >15 ug/l 30 minutes	86%	91%	.93	.86	.90
TAC >15 ug/l 45 minutes	86%	96%	.97	.84	.90
TAC >15 ug/l 60 minutes	86%	96%	.97	.84	.90
TAC >15 ug/l 75 minutes	81%	98%	.98	.81	.89
TAC >15 ug/l 90 minutes	80%	100%	1.00	.80	.89
TAC >15 ug/l 120 minutes	73%	100%	1.00	.75	.85
TAC > 25 ug/l 15 minutes	87%	91%	.92	.85	.89
TAC > 25 ug/l 30 minutes	86%	95%	.95	.84	.90
TAC > 25 ug/l 45 minutes	86%	96%	.97	.84	.90
TAC > 25 ug/l 60 minutes	81%	96%	.97	.81	.88
TAC > 25 ug/l 75 minutes	77%	98%	.98	.77	.87
TAC > 25 ug/l 90 minutes	74%	100%	1.00	.76	.86
TAC > 25 ug/l 120 minutes	71%	100%	1.00	.74	.84
TAC > 50 ug/l 15 minutes	77%	93%	.93	.76	.84
TAC > 50 ug/l 30 minutes	71%	93%	.93	.72	.81
TAC > 50 ug/l 45 minutes	70%	98%	.98	.72	.83
TAC > 50 ug/l 60 minutes	64%	98%	.98	.69	.79
TAC > 50 ug/l 75 minutes	63%	98%	.98	.68	.79
TAC > 50 ug/l 90 minutes	60%	100%	1.00	.67	.78
TAC > 50 ug/l 120 minutes	59%	100%	1.00	.66	.77
TAC > 75 ug/l 15 minutes	70%	93%	.92	.71	.80
TAC > 75 ug/l 30 minutes	69%	96%	.96	.71	.81
TAC > 75 ug/l 45 minutes	66%	100%	1.00	.70	.81
TAC > 75 ug/l 60 minutes	63%	100%	1.00	.68	.79
TAC > 75 ug/l 75 minutes	60%	100%	1.00	.67	.78
TAC > 75 ug/l 90 minutes	56%	100%	1.00	.64	.75
TAC > 75 ug/l 120 minutes	51%	100%	1.00	.62	.73
TAC > 100 ug/l 15 minutes	66%	95%	.94	.69	.79
TAC > 100 ug/l 30 minutes	61%	100%	1.00	.67	.79
TAC > 100 ug/l 45 minutes	59%	100%	1.00	.66	.77
TAC > 100 ug/l 60 minutes	56%	100%	1.00	64%	.75
TAC > 100 ug/l 75 minutes	53%	100%	1.00	63%	.74
TAC > 100 ug/l 90 minutes	51%	100%	1.00	62%	.73
TAC > 100 ug/l 120 minutes	46%	100%	1.00	60%	.70

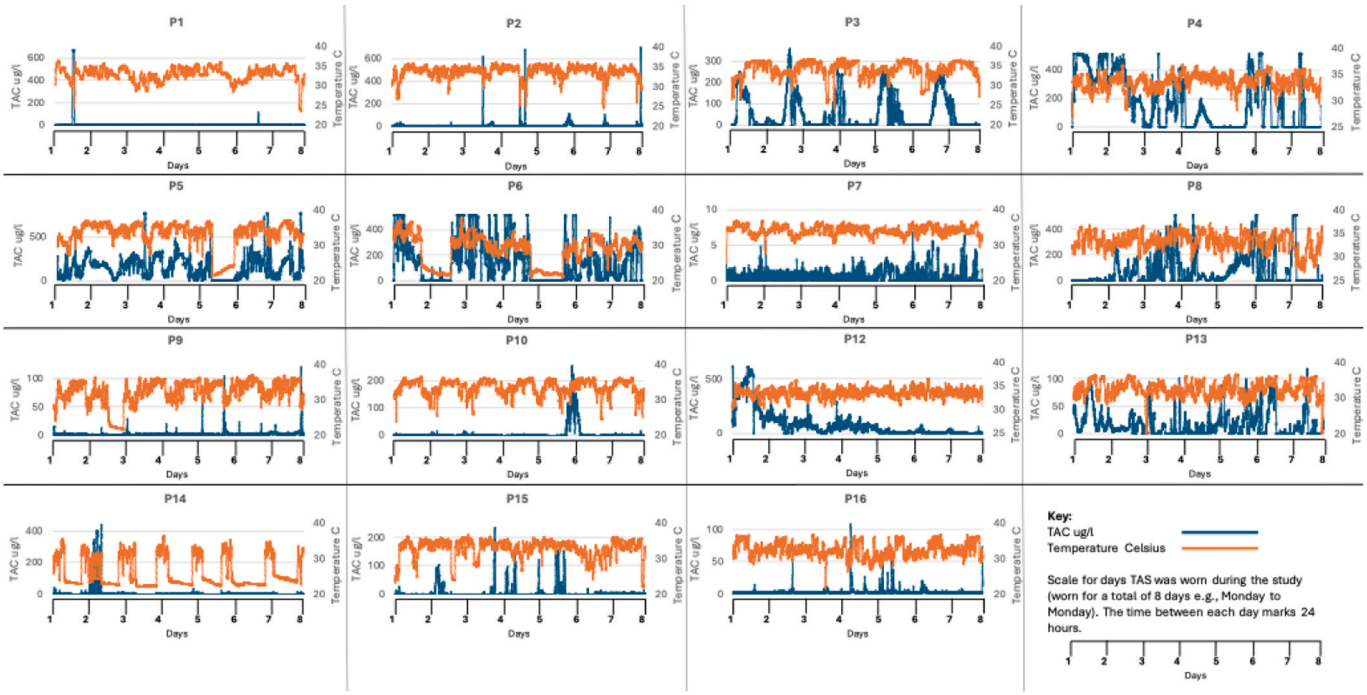

Fig. 2. Participants TAC and temperature data over the course of one-week TAS wear Fig. 2. All participant TAC and temperature data for the one-week TAS wear. Participant 11 is not included in this Figure as they ended their participation early. The blue line is TAC ug/l on the primary axis and the orange line is temperature (Celsius) on the secondary axis.

consistent, measurement of alcohol consumption in the context of alcohol treatment. This could include evidence of reduction or abstinence, which in turn could motivate the patient, or demonstrate commitment to service engagement for funded treatment (Ariss et al., 2022; Barnett, 2015; Brobbin, Deluca, Parkin, et al., 2023). Yet, if the patient has been responsible for looking after their TAS and used it correctly it would be unfair for them to be disadvantaged, penalised or encounter consequences due to missing data, through device error. This could demotivate the patient, especially if they lose out on a contingent reward or benefit. When considering TAS use for a CM reward-based programme, decisions on how to deal with missing data will be required beforehand. We found that the number of days with a period of five hours or more of missing data was 45 days (35.7%) and days with an hour or more of missing data increased to 57 days (45%), almost half the study period. Also, in this context, our data supports using a higher TAC threshold which prioritises specificity over sensitivity to minimise false positives.

There are implications for removals detected by the temperature sensor. We took a measurement of 29 ^{0}C or below as the threshold for detecting the device being removed. However, sometimes the device might not be removed but simply become loose. Wearing the device loose is not guaranteed to produce accurate readings. During TAS training, it was emphasised how important it was to wear the TAS correctly. There may be times TAS becomes caught on clothing without the wearer noticing or those with memory impairment may not remember this (White, 2003). Again, it would be unfair that the client could be disadvantaged. But these scenarios need to be considered. Outpatient alcohol treatment is completed voluntarily, and this TAS would be no different. As with other forms of treatment, the patient's motivation, willingness to change and other individual factors will impact their treatment use and engagement (Adamson et al., 2009; Anglin and Hser, 1990; Hser et al., 2001).

SCRAM is the only TAS being used widely in real-world settings, within criminal justice settings, in the US and UK. TAS use within these criminal justice settings also involves the use of sanctions for programme breaches (alcohol consumption). There are no TAS currently being used routinely for alcohol treatment. Research has posited TAS as a useful clinical tool and earlier studies have shown that TAS in combination with CM for alcohol reduction or abstinence can be successful (Barnett et al., 2011, 2017; Dougherty et al., 2014, 2015). TAS offer a way to continuously support behavioural reinforcement interventions, that are known to be effective for substance use treatment (Petry, 2011; Pfund et al., 2021; Prendergast et al., 2006; Stitzer and Petry, 2006). Particularly as the Skyn also has the potential for near real-time data output, it could help deliver these interventions close to real-time drinking events (Bae et al., 2018; Businelle et al., 2020; Nahum-Shani et al., 2018). The continuous 24/7 data collected could provide a depth of information not previously possible for community detoxification. This means that interventions could potentially become even more personalised for each individual and adjust in response to changes in the wearer's alcohol consumption patterns and provide early detection of relapse. However, alongside being accurate and reliable, TAS would also need to be investigated if TAS are practical, feasible and considered acceptable to wear for a week, or longer, by people who wear the device (Brobbin et al., 2023, under review).

5.1. *Strengths and Limitations*

Strengths of our study include demonstrating the use of the BACtrack Skyn over a week with individuals currently diagnosed with alcohol dependence and receiving alcohol treatment. Despite the frequent research visits, there were ample instances when participants wore the TAS without the presence of a researcher. This enabled us to explore how this population integrates and utilises the TAS in real-life settings, including their natural alcohol consumption patterns. Despite alcohol service staff concerns and previous studies suggesting dropouts and loss of devices, through the study design and the relationship built between the researcher and participants, we were able to achieve 100% meeting attendance and TAS return. We also provided sufficient training at the beginning of the week, meaning no participant needed additional help to use the TAS. As participants were shown to be engaged with the study and felt confident in wearing and using the TAS, this further supports the

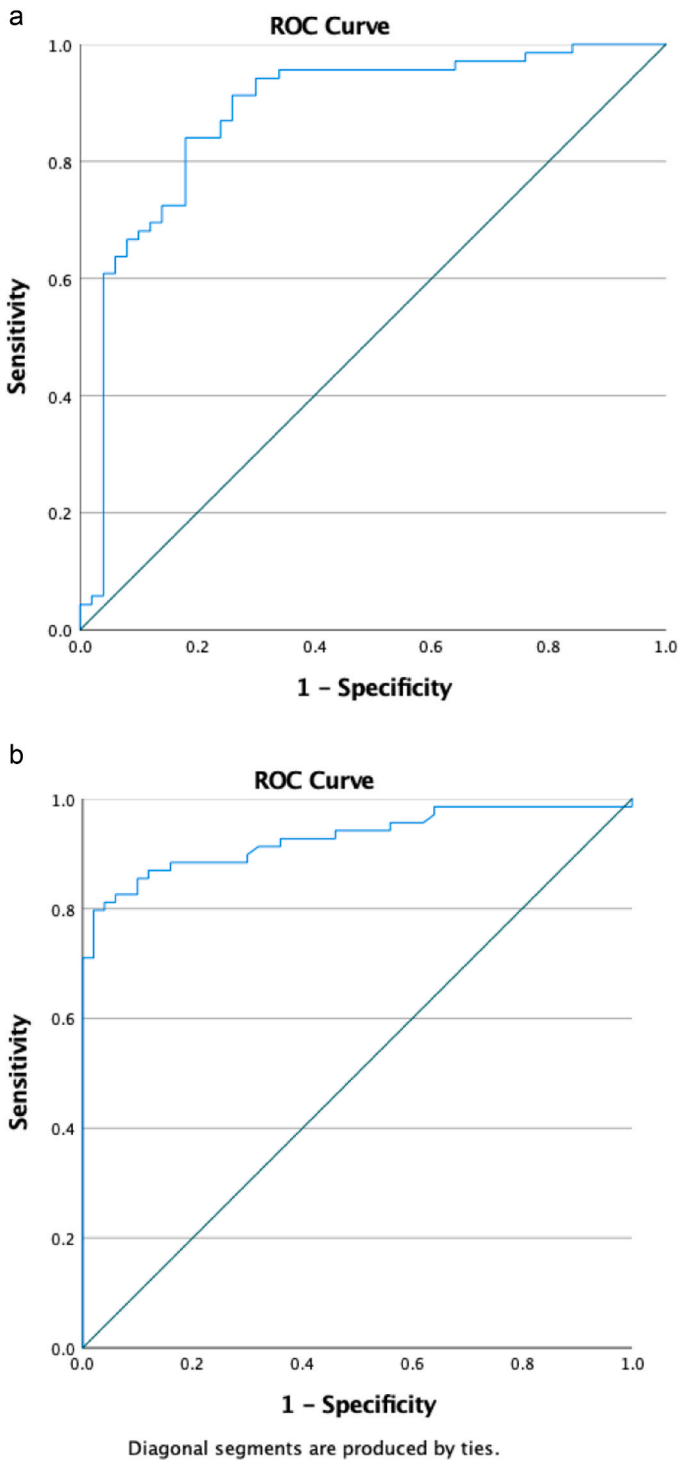

Fig. 3. a) ROC curves for criteria of daily peak TAC to TLFB. Fig. 3b) ROC curves for criteria of average daily TAC to TLFB.

use of TAS to monitor alcohol consumption in this population in the future.

Limitations of this study include that those who consented to participate were willing to wear TAS technology. Those that were not willing to wear it from the start were excluded and were not able to complete the post-survey. Also, we did not ask participants to record when they removed the device, the reason, or for how long. If we knew this, we could then ignore these time points as 'device removal' issues. However, this could increase the burden on the participant. It could not be guaranteed that the participant accurately reports times or reasons for removals.

The data reported in this manuscript is one part of the study that was conducted. In this same study (22/LO/0426), participants also completed a semi structured interviews until data saturation was reached. While this paper reports the quantitative accuracy results, our sample size was influenced by this qualitative aspect. The interview data can be found in our linked paper Brobbin et al., (2023), under review.

5.2. *Conclusion*

This is one of the first studies investigating BACtrack Skyn with alcohol-dependent individuals and the first to do so in UK services. We found high rates of engagement and compliance with no device losses. Side effects were generally minimal to mild severity and even those who reported side effects were willing to wear it again and for longer. TAS and self-report TLFB data showed a high sensitivity and specificity of Skyn compared to self-report. This study supports the use of TAS technology with people who attend alcohol treatment services but further consideration of the best practice use of TAS should be considered to minimise our highlighted challenges and limitations.

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Author statement

EB: conceptualisation, methodology, analysis, investigation, resources, data curation, project administration, visualization, drafted and revised the article; **PD:** conceptualisation, methodology, analysis, supervision, revised the article; **SC:** analysis, revised the article; **SP:** conceptualisation, methodology, supervision, revised the article; **CD:** conceptualisation, methodology, analysis, supervision, revised the article.

CRediT authorship contribution statement

Brobbin Eileen: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft. **Drummond Colin:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Parkin Stephen:** Conceptualization, Supervision, Writing – review & editing. **Coulton Simon:** Formal analysis, Writing – review & editing. **Deluca Paolo:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

None to declare.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.drugalcdep.2024.111122.

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