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iMStrong: Deployment of a Biosensor System to Detect Cocaine Use

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Abstract

Biosensor systems are increasingly promoted for use in behavioral interventions. Portable biosensors might offer advancement over self-report use and can provide improved opportunity for detection and intervention in patients undergoing drug treatment programs. Fifteen participants wore a biosensor wristband capable of detecting multiple physiologic markers of sympathetic nervous system (SNS) arousal for 30 days. Urine drug screening and drug use self-report were obtained twice per week. A parameter trajectory description method was applied to capture abrupt changes in magnitude of three measures of SNS activity: Electrodermal activity (EDA), skin temperature and motion. Drug use events detected by the biosensor were verified using a triad of parameters: the biosensor data, urine drug screens, and patient self-report of substance use. Twelve positive cocaine urine screens were identified. Thirteen self-reported episodes of cocaine use were recorded. Distinct episodes with biometric parameters consistent with cocaine use were identified on biosensor data. Eleven potential cocaine use episodes were identified by biosensors that were missed by both self-report and drug screening. Study participants found mobile biosensors to be acceptable, and compliance with the protocol was high. Episodes of cocaine use, as measured by supraphysiologic changes in biophysiometric parameters, were detected by analysis of biosensor data in instances when self-report or drug screening or both failed. Biosensors have substantial potential in detecting substance abuse, in understanding the context of use in real time, and in evaluating the efficacy of behavioral interventions for drug abuse.

Keywords

Mobile biosensing; Drug abuse; mHealth; Biosensor system; Parameter trajectory

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Introduction

Wearable, non-invasive biosensors, with their portability and low cost, have been applied to a variety of clinical scenarios such as post-traumatic stress disorder, drug addiction, HIV therapy, stress and epilepsy [1–5]. One potential application of biosensor systems that has yet to be studied extensively is their use in evaluating the efficacy of behavioral interventions for problematic substance use, a chronic disorder characterized by craving and relapse to drug use even after prolonged abstinence [6, 7]. Interventions for substance abuse typically rely upon a combination of pharmacologic and behavioral interventions; for stimulants such as cocaine, however, no FDA-approved pharmacologic interventions exist [6, 7]. Treatment for compulsive cocaine use relies purely upon behavioral interventions. Although some cocaine-dependent patients will respond well to behavioral interventions, treatment for cocaine dependence often suffers from high rates of relapse [8]. The failure of existing psychosocial and behavioral treatments highlights the importance of assessing sobriety which is currently monitored via self-report and testing biological matrices such as urine or blood [8].

Unfortunately, both methods suffer from serious limitations. The window of detection for urine drug screening is limited to 48–72 h after use. Self-report is subject to recall bias, distortion, and deliberate under-reporting due to psychosocial and legal motivational factors. The limitations inherent in current strategies for detecting drug use highlights the urgent need for improved methods for assessing an individual's propensity for drug use and the environmental, psychosocial, and contextual factors that heighten the potential for relapse [7, 9].

One underutilized source of data regarding behavior is the sympathetic nervous system (SNS). SNS activity escalates during stressful conditions, as when riding a roller coaster at an amusement park, participating in a job interview, or meeting a significant other's parents for the first time [10, 11]. An even more dramatic change in SNS response occurs following cocaine use which produces a catecholamine surge that triggers supra-physiologic SNS activity [12]. Although several surrogate measures of SNS activity exist, three that can be easily measured by portable biosensors are skin temperature, electrodermal activity (EDA) and locomotion [3, 13]. The manifestations of these physiologic changes can be measured and recorded multiple times per second throughout the day using small biosensors in a form factor similar to a wristwatch. This allows for a real time, non-invasive monitoring strategy for measuring physiologic changes that can occur in multiple contexts.

The striking increases in EDA, greater locomotion, and decreased skin temperature effects that follow cocaine use support the application of mobile biosensors to detect episodes of substance abuse in natural environments [14]. Biosensors can also be linked via Bluetooth to mobile computing platforms such as smartphones so that patients in treatment can record contextual information regarding drug use and thus better elucidate the bio-psycho-social influences on a cocaine user's propensity for relapse. These unique abilities of biosensors yield a novel approach to facilitating behavioral change.

The purpose of this investigation, known as iMStrong, is to identify biophysiometric patterns associated with cocaine use in natural environments. To evaluate this, we deployed portable biosensor among patients undergoing treatment for cocaine dependence. These non-invasive biosensors are capable of detecting skin temperature, EDA, and physical acceleration in three dimensions that serve as surrogate markers for sympathetic nervous system activity. Given the striking physiologic changes that follow cocaine use, we hypothesized that this technology could detect episodes of relapse in cocaine dependent individuals. This approach could also be used to identify episodes of craving as well.

Materials and methods

Enrollment

This study was approved by Institutional Review Board at the University of Massachusetts. All participants were recruited from local community-based or outpatient treatment facilities for substance abuse rehabilitation. All participants met the following inclusion criteria: Age greater than or equal to 18 years old, diagnosis of cocaine dependence, ability to provide informed consent, and willingness to wear sensor as directed for duration of study period. Participants were excluded if they refused to utilize the biosensor and/or they demonstrated serious mental illness that would interfere with study participation or consent.

The research assistant presented the study to outpatient clinicians as well as the community-based programs, making potential participants aware of the study and all of the basic components.

Consent

Prospective candidates were briefed on the function of the device and the goals of the study, and informed consent was obtained. Participants were given a gift card of predetermined value at each visit. Over the 30 days, each individual would accumulate $240 total in gift cards as an incentive for participation.

Biosensor system deployment

Once enrolled, the participants were provided with the portable biosensor (Q sensor, Affectiva), depicted in Figs. 1a and b. The sensor continuously measures EDA (in microSiemens), skin temperature (in degrees Celsius) and three-dimensional locomotion (in units g, it SI units for acceleration). The three dimensions (X, Y and Z axes) are identical to those used to track motion by popular smartphone applications. They are defined as follows: X-axis is the anterior posterior direction; the Y-axis is the lateral direction; the Z-axis is the caudad-cephalad direction. They were given approximately 5 min of teaching on how to properly wear the sensor, to charge the sensor, and to ascertain that it was powered on and collecting data. They also received a one-page information sheet summarizing this information to keep as a reference. Participants were instructed to wear the device on their non-dominant wrist during all hours while awake only, and to remove and charge the device while sleeping.

Surveillance

The participants were enrolled in the study protocol for 30–45 days (depending on appointment timing, participant availability etc.). Participants met with study personnel twice per week for the duration of the protocol. At each visit, participants provided a urine sample for drug screening and participated in a time-line follow back interview to describe the events in the preceding 3–4 days, with a focus on drug use and/or craving. Data from the biosensor was downloaded and reviewed by study personnel, and timing of any periods of significant variation from the physiologic baseline tracing were noted.

Technology retrieval and exit interview

On the final study visit, the participant returned the sensor. A brief questionnaire was administered to evaluate their experience with the technology with regards to its overall acceptability and obtrusiveness.

Statistical analyses

Descriptive statistics were summarized for substance users' demographic background and their compliance status during the study period. We used a parameter trajectory pattern description method to depict and capture physiologic changes caused by SNS arousal. We used the following parameters for SNS arousal: electrodermal activity (EDA), skin temperature, and locomotion (including three axes of dimension, X, Y and Z). These five attributes were each included in our drug use episode detection algorithm. While the number of participants was small, the volume of data was large because we measured each attribute up to 20 times per second for 30–45 days. We computed these day-to-day SNS parameters in the following manner: Primarily, Means for all attributes; additionally, Medians, Maximums and Minimums were used to cross check the results. The absolute magnitude of change were computed for EDA and three locomotion attributes, as their abrupt heights. For skin temperature, the abrupt *decrease* arising from vasoconstriction and decreased blood flow implies potential cocaine or other SNS stimulant drug use. Using these data, we generated the parameter trajectories for each patient. Sets of unusual peaks (e.g., EDA or motion attributes) and valleys (e.g., skin temperature abruptly declining from 37 °C) were filtered out and verified with participants' urine drug screen results and self-reports on drug use. Figure 2 illustrates the algorithm of the biosensor system to drug use detection.

Results

Demographic data

Among the 15 participants, the mean age was 47 years (median=50, SD=8.6). The average number of days enrolled in the study was 35 (SD=10). Twenty nine percent of participants had been in a controlled environment in the 30 days preceding the study, including jail (*N*=1), psychiatric facility (*N*=1) and substance abuse treatment (*N*=2). The study distributions by gender, race, ethnicity, and substance abuse history and employment status are depicted in Fig. 3.

Compliance data

Ninety three percent (*N*=14) of participants completed the study and returned the biosensor upon completion of the study. The single participant who did not complete the protocol developed multiple social and medical problems that precluded ongoing participation in the study.

Percent of study days where data was captured ranged from 60 to 100 %. Four participants (27 %) had a capture rate of 100 %, meaning they wore the sensor and data was recorded on every day during the study period. The remaining 11 participants (73 %) had a capture rate of 60–99 %, indicating that the sensor was removed or failed to capture data on some days during the study period.

Sensor and participant use data

Since the median, minimum and maximum trajectories showed similar trends to the mean trajectories for our sensor data, we used the mean trajectories to showcase the drug use detection of our biosensor system. Twelve cocaine-use events were detected by urine drug screening during the study period. Thirteen self-reported episodes of cocaine use were ascertained; 12 were in agreement with the urine drug screening results, and one episode occurred without a positive urine drug screen result, as is discussed in detail below. Our parameter trajectory method assisted in detecting drug use events by capturing the actual abrupt changes in biometric data, specifically looking for simultaneous increase in EDA, increased motion and decrease in skin temperature. A biosensor signal consistent with this pattern corresponded to each of the known cocaine use events verified by urine tests. Additionally, 11 events suspicious for cocaine use were detected by the biosensors that were not captured by either self-report or urine drug screening.

Figure 4 displays three representative cases indicating potential advantages of our biosensor system over urine screen and self-reports in substance use behavioral intervention. Among three-dimensional locomotion variables, Dimension Z seems to be more sensitive and consistent in drug use detection. Therefore, graphs from Dimension Z were displayed along with Skin Temperature and EDA for all cases. In all graphs, X-axis shows the day enrolled in the study and Y-axis shows the magnitude of skin temperature, EDA and locomotion Z, respectively.

Figure 4a showcases an example of a participant who had two urine tests positive for cocaine use but failed to self-report any drug use. This participant was a 58-year-old male, with a 2 year history of crack cocaine use with no other reported history of drug use. His past medical history included coronary artery disease, hypertension and hyperlipidemia. He had no diagnosed psychiatric issues but self-reported feeling depressed and anxious. He was divorced, unemployed and lived with friends who used cocaine frequently. He had positive urine drug screens for cocaine on study days 9 and 16 but did not self-report any use. Interestingly, on study day 8 he reported significant family stress (including his children being removed from their mother’s home by social services) and on study day 14 admitted to being around friends using cocaine, two possible triggers for relapse. Our biosensor

system captured these two episodes. The first episode was on study day 9 and the second episode was on study day 14.

Figure 4b showcases where the participant self-reported cocaine use that was not reflected in her urine screen because drug use was outside the window of detection for urine drug screens. This was a 36-year-old female with a 4 year history of snorting and smoking crack cocaine, and a prolonged history of polysubstance abuse including marijuana, alcohol, and hallucinogens. Her medical history included hypothyroidism, and her psychiatric history included diagnoses of bipolar disorder, depression and post-traumatic stress disorder. She was single, unemployed due to psychiatric disability, and lived alone. She self-reported cocaine use on study day 28, however the subsequent urine drug screen obtained 4 days later on study day 31 was negative. Her sensor data indeed depicted the abrupt changes in skin temperature, EDA and locomotion Z on study day 28.

Figure 4c showcases another advantage of biosensor for detecting potential drug use episode over self-reports and urine screen. This participant was a 29-year-old male with a 10 year history of polysubstance abuse including cocaine, alcohol, sedative hypnotics, marijuana and hallucinogens. He had no medical problems, and had previous psychiatric diagnoses of depression and anxiety. He had completed an inpatient drug rehabilitation program within 1 month of entering the study. He was single, unemployed, and lived with a partner who actively used crack cocaine. One study day 1 he reported feeling very anxious because his friends were using crack cocaine around him and on study day 2 the biosensor detected abnormal changes and in magnitude of three biometric parameters. The episode was not self-reported nor screened positive by the urine tests. The subsequent urine sample was obtained on study day 5, 3 days after the suspected use, and thus likely would not have detected cocaine use. This scenario highlights a potential advantage of biosensors to identify questionable incidents and provide an opportunity for intervention.

Participant perception

Figure 5 summarizes participant responses to the exit interview.

The overall consensus on user experience with the biosensor wristbands was positive. Several participants remarked about the improved awareness while wearing the bracelet; one patient commented that “it was a good experience, and it made him more aware—and may consider [the biosensor] as a deterrent from using.” However there were also several patients who had difficulty with the biosensor not working and were frustrated with having to troubleshoot those issues.

Reactions of friends and family to the biosensors were mostly either curious or indifferent about why the participant was wearing it. Two participants, however, reported that friends or family perceived the biosensor as an indicator that he or she was in trouble or under house arrest—but after explaining what it was, the family was supportive and mindful of its use. Participants also reported that many individuals who were not friends or family thought the biosensor might be a GPS device.

About half of participants (7/15) indicated that the sensor made them less likely to use drugs as it made them more mindful of their actions and “would look at sensor, and would think about prison”. Of the 8 participants who felt that the sensor would not make them less likely to use drugs, commentary included “I still used” and “If I was going to use, I was going to use and it didn’t matter what was on my wrist. ”

Most participants did not report doing anything differently because he or she was wearing the wristband and it was “life as usual.” One participant, however, reported that he wore more long sleeved shirts than usual; another described being more “cautious” while working.

Discussion

Data from our iMStrong project demonstrates the ability for biosensors to detect episodes of cocaine use based on detection of increased EDA, increased locomotion and decreased skin temperature. This constellation of findings occurred when participants were positive for cocaine based on self-report, urine drug screening or both. Interestingly, episodes corresponding to this profile were also present on occasions where no report of use or positive drug screen occurred. This case potential demonstrates the advantage of real time detection using biosensor system over urine tests and self-report, because the urine test captures a historical drug use event in about past 48–72 h and is dependent on the concentration of drug present.

Technology only provides benefit if the target population agrees to engage in its use; participant acceptability and experience is, therefore, a leading priority in the evaluation of this method. Overall, participant perception of the technology was positive, stigma associated with the device was minimal, and acceptability was high. All participants were willing to wear the sensor beyond the study period, indicating its potential for long term application.

Potential applications of biosensor technology extend beyond the ability to detect drug use since biophysiometric data can be wirelessly transmitted to mobile devices where detection algorithms can be programmed to trigger interventions such as a phone call to a counselor, sponsor or family member. Data can also be used to more reliably assess the efficacy of given interventions over time and adjust treatment plans accordingly.

Our study had several limitations. One was its reliance on technology to capture data in natural environments. We identified multiple instances where, instead of a continuous data stream, the device recorded multiple short time segments thought to be related to the device turning on/off inadvertently. The discontinuity in the dataset increases the risk for missed episodes of relapse. With our protocol, missing data could not be ascertained until the next clinic visit when data was downloaded, at which point considerable data might have been lost. To correct this shortcoming, manufacturers will need to generate more robust biosensors that can survive drops, immersion, corrosion from perspiration, and other environmental effects before truly continuous data can be ensured. A second limitation stems from our method of analysis. Although it could reserve and depict abrupt changes, our parameter trajectory description was built upon offline data and could be further developed

into an automated algorithm by considering missing data in the real time drug-event detection environment [15–17]. Finally, participants wore a sensor on the non-dominant wrist only, and it is unclear whether data collected on the contralateral side would have been more or less robust. Further data collection will be required to incorporate bilateral readings and define the expected differences.

Portable biosensors have tremendous potential to extend our ability to observe episodes of drug use as they occur and to intervene in real time. Our data demonstrate that the sensors are acceptable to participants; compliance with their use in natural setting is high. Biometric data correlates with known use episodes, and may detect episodes unrecognized by standard methods. Further investigation is required to develop robust algorithms to accurately identify likely use events and to trigger real time interventions to realize the full potential of this technology.

Acknowledgments

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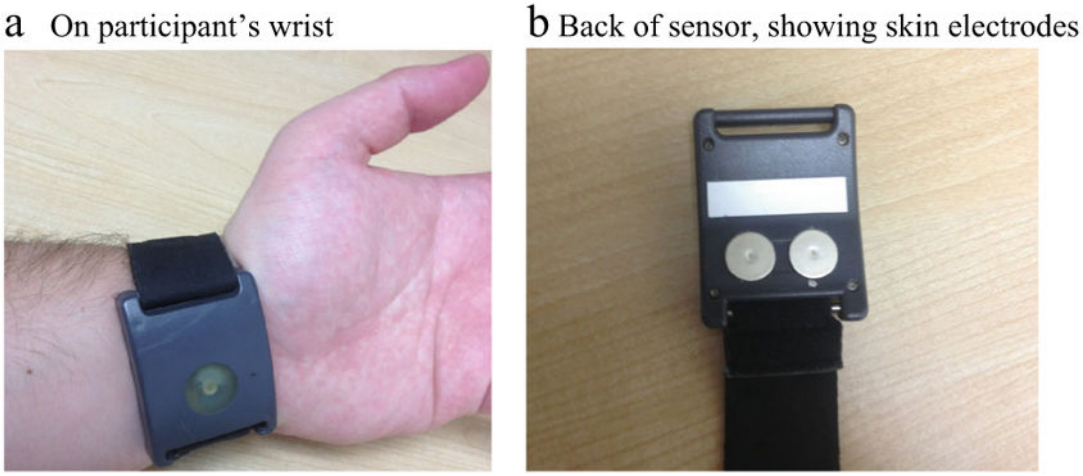


Fig. 1.
Affectiva Q sensor **a** On participant's wrist b Back of sensor, showing skin electrodes

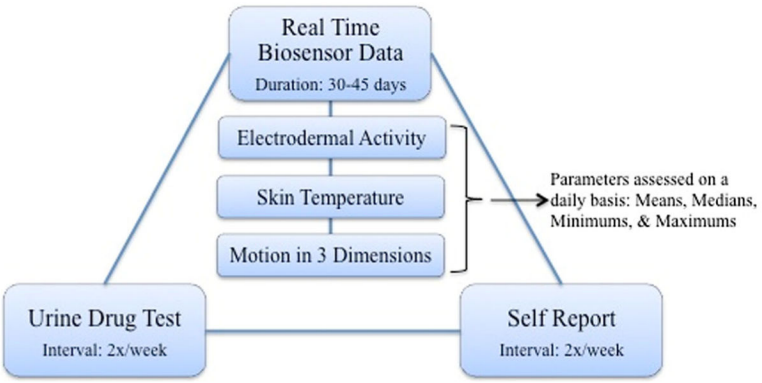


Fig. 2.

Analytical approach to assess iMStrong biosensor system in drug use detection

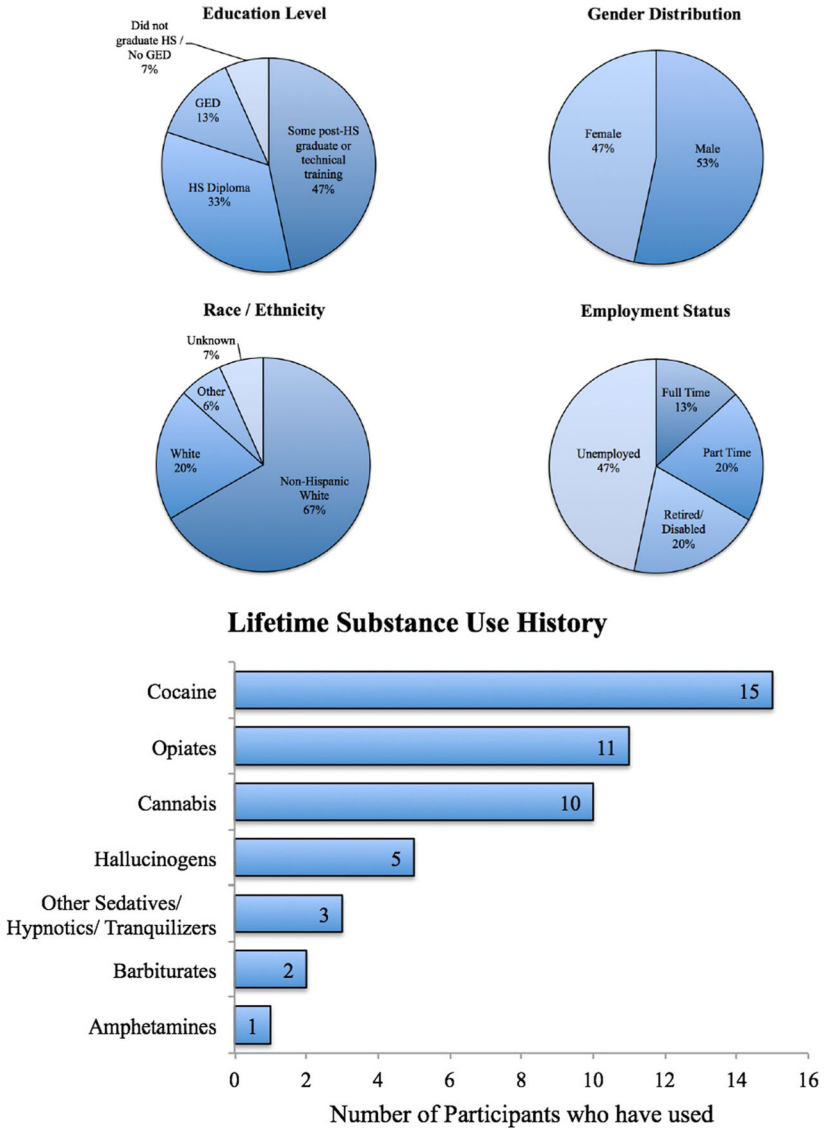
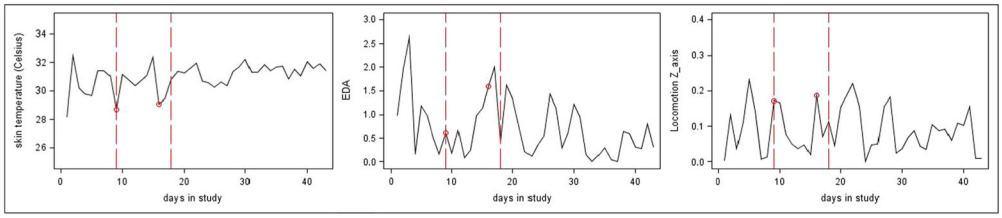
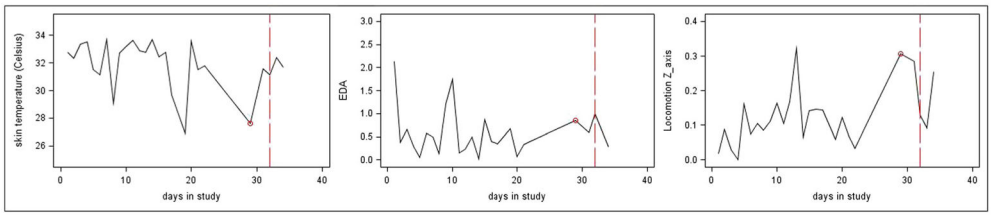


Fig. 3.
Demographics

(a) Biosensor captured two drug use episodes reflected in urine screen but not self-reported



(b) Biosensor captured drug use episode self-reported but not reflected in urine screen



(c) Biosensor captured suspicious drug use episode neither self-reported nor reflected in urine screen

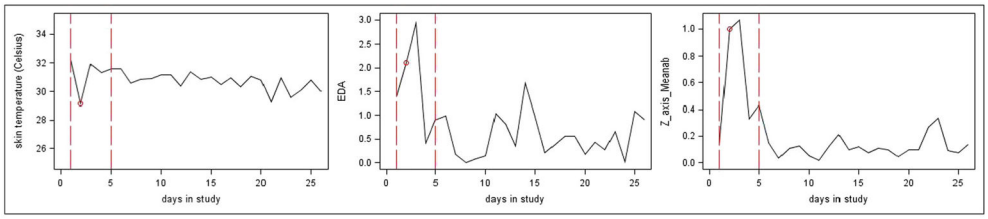


Fig. 4.

Drug use detection by iMstrong biosensor system (Note: *Red dashed lines* represent urine screen dates of interest, *red dots* represent drug use episodes of interest) **a** Biosensor captured two drug use episodes reflected in urine screen but not self-reported **b** Biosensor captured drug use episode self-reported but not reflected in urine screen **c** Biosensor captured suspicious drug use episode neither self-reported nor reflected in urine screen

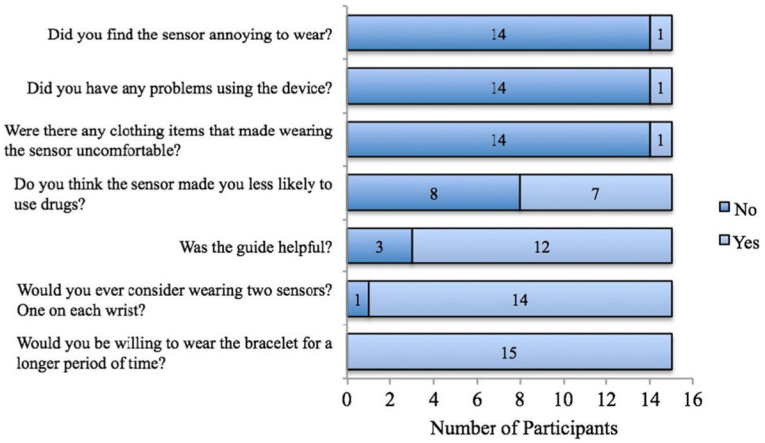


Fig. 5.
Biosensor user experience