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Review article

Biological organisms as volatile compound detectors: A review

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ABSTRACT

The detection and identification of volatile compounds is essential to the successful undertaking of numerous forensic analyses. Biological olfactory systems possess the extraordinary ability to not only detect many thousands of distinct volatile compounds (odors) but also to discriminate between them. Whole-organism biological sensors, such as detection canines, have been employed in forensic science as volatile compound detectors for many years. A variety of insects including bees, wasps, and moths, which have also been shown to detect volatile compounds of forensic significance, have been investigated for their potential application in field-based detection systems. While the fundamental aim for many developers of portable instruments is to replicate the remarkable ability of biological olfactory systems, such analytical equipment is yet to possess the detection and discriminatory powers achieved by biological sensors. Recent literature reveals an increasing interest in olfactory receptors – the biological components that impart olfactory ability – for detecting volatile compounds associated with forensically significant substances such as explosives and illicit drugs. This paper reviews the literature regarding the current, and potential future, use of biological organisms as sensors for forensic science applications.

Contents

1. Introduction

Volatile compounds (VCs) are significant constituents within a range of substances commonly encountered in forensic science (e.g. explosives, illicit and abused drugs, ignitable liquids, etc.). The detection of VCs may be exploited for a variety of purposes, such as: security screening (e.g. detection of illicit drugs, explosives and/or other prohibited items in baggage), assisting in investigator efforts (e.g. locating clandestine graves, ignitable liquid residues at fire scenes, etc.), or chemical analyses (e.g. analysing the headspace of fire scene debris for the presence of ignitable liquid residues). In many instances, the primary objective is to detect the active or most abundant VC components (e.g. the active drug in a drug

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sample); however, it is often the detection of by-products or other manufacturing artifacts on which the success of particular techniques rely.

The extraordinary ability of biological organisms (i.e. animals) to detect, recognize, locate, and discriminate between target materials via VCs is well documented, having been researched thoroughly in various species [1–5]. Whole-organism biological sensors have been employed as VC detectors in various ways for numerous years [2,4,6–9]. For example, canaries were the original chemical sensors utilized for detecting carbon dioxide in mines [10]. Additionally, the detection canine (the most well-known and widely used biological sensor) is successfully employed for rapidly searching large scenes for the presence of target VCs in a variety of forensic areas [7,9,11–14]. There is also significant interest in the potential employment of other biological organisms, such as rats [15,16], wasps [17,18], and bees [6,19]. The advantages of biological organisms as VC detectors have been reported by many authors [11,20–22]; however, their limitations are also well documented [6,7,18,23,24].

In comparison to more conventional physico-chemical detectors (e.g. flame ionization or surface acoustic wave detectors) the actual operational employment of whole organisms as VC sensors, with the exception of canines, is relatively low. However, because of the significant advantages of biological organisms, such as their sensitivity and selectivity, there has been continued interest in their wider application for forensic purposes. This paper reviews the published literature regarding the wider applications of whole organisms and biologically derived VC sensors and highlights their current or potential future use in forensic fields.

2. Vertebrates

Chemical cues (odors) provide information about food, mates, offspring, predators, prey, and pathogens; they are also employed for communication purposes [21,22]. Therefore, well developed olfactory abilities are essential for survival for the majority of animals [20]. The olfactory systems of vertebrates are highly sophisticated, imparting such discriminatory capabilities that thousands of VCs are perceived as being distinct odors [21]. Highly sensitive and selective olfactory abilities have been demonstrated in a variety of vertebrates [25–27]; however, their use as chemical sensors has been limited primarily to canines, potentially due to a lack of knowledge regarding their trainability as well as limitations with their physical employment. Only recently has there been interest in other vertebrates such as rats [15,16,28].

2.1. Canines

The most well-known and widely employed biological sensor is the common canine, *Canis lupus* var. *familiaris*. Reported as being significantly more sensitive and selective than human olfaction, the canine's extraordinary sense of smell has been utilized in numerous areas of law enforcement for the detection of VCs of forensic interest. For example, detection canines have been used for detecting illicit drugs, land mines (Fig. 1a) [14], guns, ignitable liquid residues [12,24], explosives [11,23], clandestine burials [13,29], and controlled goods such as illegally imported food or ivory [13,30]. Canines have also been used for tracking purposes, such as for locating criminals, missing persons and disaster victims, as well as for providing a visual deterrent for potential illegal activities [7,9,14]. As a result, the detection canine and its handler offer significant contributions to the real-time detection of VCs of interest.

Training detection canines typically involves: imprinting the odors the canine is supposed to detect; using representative odors that the canine should not alert to but which are likely to be encountered in their working environment; and performing regular "refresher" training to ensure on-going reliability of results [31]. Indications as to the presence of the target substance include either passive or active behavioral alerts. Passive alerts involve the canine sitting near the odor source, whereas active alerts (also referred to as aggressive alerts) involve the canine scratching at the odor source. Active alerts are considered by some handlers to provide greater "pin-point" accuracy and are used typically for the detection of illicit drugs. However, such alerts are highly dangerous if explosives and/or landmines are being targeted; therefore passive alerts are more appropriate for such circumstances.

As reported in the literature, the primary advantages associated with the use of detection canines include their agility [30], their ability to rapidly and thoroughly search large areas [32,33], their olfactory sensitivity that allow them to detect and discriminate between target and non-target substances even at low concentrations [24,31], and their scent-to-source capabilities that allow them to pinpoint areas of highest concentration [9,11,31]. Due to these advantages, the deployment of detection canines is unlikely to decrease in favor of field portable instrumentation in the near future. However, a study of the literature also reveals several limitations. For example, successful detections are highly variable from canine to canine [7,29], and depend significantly on their training [11,30], hormonal changes, possible infections, illness [9,11], and environmental conditions [32,34]. Additionally, detection canines are expensive to train [9,33,35] and require ongoing maintenance and refresher training [14]. They can also suffer from olfactory fatigue, which is the loss of sensitivity and selectivity due to repeated and prolonged exposure to the same odor [29,30,34].

While the deployment of detection canines is widely accepted in the forensic and law enforcement communities, questions regarding their accuracy, reliability, and validity have been raised and are regularly debated [9,36,37]. Research regarding the accuracy of individual detection canines in a range of detection scenarios can illustrate great variability, with some authors reporting successful detections ranging between 40% and 100%

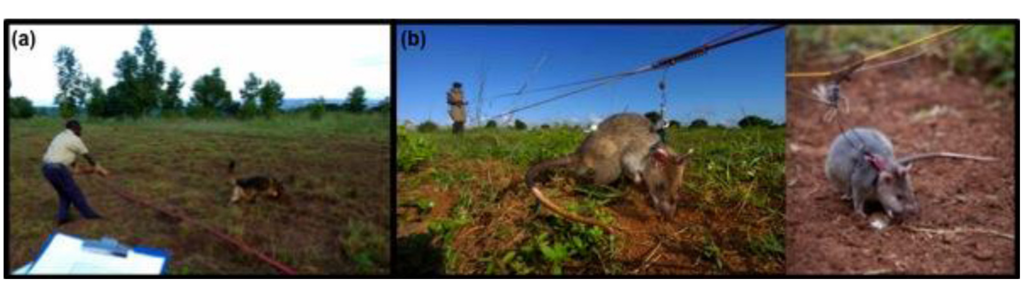

Fig. 1. Vertebrate volatile compound detectors. (a) Detection canine in training. (b) African pouch rat trained for landmine detection. Images reproduced with permission from APOPO [57].