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# Explosives detection by military working dogs: Olfactory generalization from components to mixtures

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ABSTRACT

The training of scent detection dogs using samples of explosives or their chemical precursors is a well-established and documented practice. However an area of canine odor detection that remains under-studied regards a trained dog's perception of an explosive odor when more than one odorant is combined to produce a mixture. The first objective of our study was to determine whether training adult Labrador Retrievers ($n = 20$) to detect the scent of chemically pure potassium chlorate (PC) was sufficient to produce generalization to PC-based explosive mixtures that contained a novel component. We found that the majority of dogs (87%) trained with pure PC alone did not correctly signal the presence of one or more of four PC-based explosive mixtures. Our second objective was to determine whether training dogs using the separated components found in the PC-based explosives would subsequently enhance detection. Dogs were then trained using a novel static odor delivery device that safely segregated the PC and non-PC components and presented a merged odor to the dog. A statistically significant improvement in percentage of dogs detecting PC-based mixtures after training with the separated components compared to training with PC alone was seen with Mixture 1 (27–100%, $P < 0.0001$), Mixture 2 (40–81%, $P = 0.0229$), Mixture 3 (38–94%, $P = 0.0004$), and Mixture 4 (69–100%, $P < 0.005$). The results of this study highlight the potential limitations of dogs trained to detect a single odor to then recognize the odor when mixed with other substances. The odor delivery device developed for this study represents an important and effective training option that may reduce the need for using a final PC explosive mixture in canine training.



## 1. Introduction

It is well known that the domesticated dog possesses highly developed olfactory abilities. Because of their keen sense of smell, dogs are extensively used to detect a broad variety of substances including narcotics (Adams and Johnson, 1994; Dean, 1972), human remains (Lasseter et al., 2003), cancers (Cornu et al., 2011; Pickel et al., 2004; Walczak et al., 2012; Willis et al., 2004), cows in estrus (Fischer-Tenhagen et al., 2011; Kiddy et al., 1978), and bed bugs (Pfiester et al., 2008). Another well-established role for dogs is scent detection of land mines, improvised explosive devices (IEDs), undetonated munitions, and other explosive materials that pose a risk to civilian and military populations (Furton and Myers, 2001; Gazit and Terkel, 2003; Harper et al., 2005; Jones, 2011). In addition to effects on civilian populations, roadside bombs, suicide car bombs, and other IEDs have caused the majority of American combat casualties in Iraq and Afghanistan (Wilson, 2007). Detection of these explosives by dogs and their ultimate removal by trained personnel can reduce civilian and military casualty rates and can reopen land for farming and other purposes (Faust et al., 2011; Watts, 2009). Despite the widespread use of dogs for scent detection, questions

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remain about the underlying processes of explosive scent detection in this and other species.

Training dogs to detect explosives presents several challenges. First, the types of explosives found in IEDs reflect local availability and can vary widely from region to region. Explosives commonly found in IEDs include organics (e.g., 1,3,5-hexahydro-1,3,5-trinitrotriazine [RDX]; 2,4,6-trinitrotoluene [TNT]), inorganic oxidizers (e.g., ammonium nitrate [AN], potassium chlorate [PC]), or a combination (e.g., Amatol – a RDX and AN mixture) (Kopp, 2008). Further, the use of homemade explosives (HMEs) has recently become more common than commercial and military explosives (Östmark et al., 2012). Consequently, the absolute and relative amounts of explosive precursors found in HMEs can vary widely. A second challenge is presented when the base explosive is further modified with additional gelling agents (e.g., wax or petroleum jelly), fuels (e.g., diesel fuel or kerosene), or extraneous distracting odors (Kopp, 2008). Therefore, most target (explosive) odors encountered by dogs under field conditions are comprised of a combination of many different substances (Harper et al., 2005), which may differ from those used in training. Learning to respond upon detection of a trained odor, then, may not generalize to detection of novel odor combinations. Thus, generalization from trained components to novel configurations, such as mixtures composed of trained and untrained odors, is an important feature of canine scent detection. The concept of generalization, in which an animal must efficiently and appropriately respond to novel stimuli based on prior experience with different stimuli, has been extensively studied (Ghirlanda and Enquist, 2003; Rilling, 1977; Spence, 1937); however, olfactory generalization of compounds of military interest in dogs remains largely unexplored (Johnston, 1999).

Generalization between a stimulus compound (e.g., a tone and a click presented together) and its elements generally occurs in one of two ways (Bouton et al., 2012). Elemental, or analytical, processing occurs when each element in the compound forms individual stimulus–response associations, which are retained regardless of combining with other stimuli (Rescorla, 1972). In regards to olfactory processing, if combining two or more odorants does not alter their individual properties such that the original odors remain identifiable in the resulting mixture, conditioned responses to the individual odors should generalize to the mixture (Linster and Smith, 1999). Alternatively, when conditioned stimuli are combined the resulting compound may be perceived as a novel configuration (Pearce, 1987), referred to as configural or synthetic processing. Odorants may combine to create a novel, blended mixture in which individual characteristics of each odorant are altered, creating the perception of a new and unique odor. In this case, conditioning to an individual component of the mixture does not produce generalization to a mixture that contains the component, and vice versa (i.e., conditioning to a mixture does not produce generalization to the individual components presented individually) (Derby et al., 1996; Laing and Francis, 1989; Staubli et al., 1987). The degree of generalization from components to mixtures may vary depending on a number of factors including the particular physicochemical properties and identities of the odorants (Derby et al., 1996; Kay et al., 2005; Laska and Hudson, 1993; Linster and Smith, 1999), the complexity of the mixture (Livermore and Laing, 1998a), the relative intensities of the odors (Livermore and Laing, 1998b), and olfactory enrichment (Mandairon et al., 2006).

Our study addressed several of these challenges. In our experiment we explored whether dogs trained to detect one component of an explosive will correctly detect a novel mixture containing that component. Our second experiment assessed the performance of dogs trained to reliably detect the components of a mixture using a novel device that maintained separation of the components in distinct compartments while presumably producing a merged odor presentation. The use of this device addresses the need to develop training aids that can be handled safely and yet provide the representative odor profile of the explosive of interest.

## 2. Animals, materials and methods

### 2.1. Animals

Nine male and 11 female field-trial-bred Labrador Retrievers ranging from 2 to 5 years in age were used. All dogs were procured by a private military working dog training firm (K2 Solutions, Southern Pines, NC, USA) from field-trial-breeding kennels throughout the United States (USA). Dogs were individually housed in 4.6 m × 1.5 m outdoor kennels at the K2 Solutions Canine Training Center (K2) located in Southern Pines, NC, USA. This facility is designed, equipped, and operated to comply with Title 9, Code of Federal Regulations, parts 1–3 and with the USA Department of Defense (DoD) Directive 3216.01 to guarantee the humane, safe, and necessary use of dogs. Animals were fed twice a day with commercial adult large breed dog food (Purina ProPlan, St. Louis, MO, USA) and had unlimited access to water. Experienced K2 trainers carried out the training and handling of the dogs for the duration of the study. All experiments were performed during a 5-week period under ambient weather conditions. Maximum daily temperatures ranged from 13 to 33 °C (daily maximum mean temperature = 27 °C). All procedures were approved by the North Carolina State University (NCSU) Institutional Animal Care and Use Committee.

### 2.2. Odorants and containers

Odor delivery was accomplished using a custom-built inverted "T"-shaped odor delivery device (Fig. 1). The odor delivery device was constructed using commercially available 7.62 cm diameter polyvinyl chloride (PVC) pipe fittings (JM Eagle, Los Angeles, CA, USA). The two terminal end-caps of the "T" allowed for the placement of PC-based materials of interest (one or both arms were used depending upon the experimental phase). Each terminal end-cap was attached to a 45° elbow which was joined to a "tee" joint fitting that terminated with a drain fitting and perforated drain cover lid. Separate odor delivery devices were used