Cigarette butts form a perceptually cryptic component of song thrush (*Turdus philomelos)* nests

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Abstract Bird nests often contain objects produced and manipulated by other animals, including human rubbish. The function, if any, of these items remains unclear, and it is unknown whether they might serve a signalling role to increase the conspicuousness of the nest lining or contribute to its crypsis. We located several nests of the introduced song thrush (*Turdus philomelos*) in New Zealand containing discarded cigarette butts. These items were embedded into the dried mud-matrix of the nest and appeared visually inconspicuous to the human observer. However, human and avian visual sensitivities are dramatically different. We used full-spectrum reflectance spectrophotometry, combined with perceptual modelling of the avian visual system to assess the contrast between mud lining, garbage, and the colours of thrush eggs. Our analyses confirmed that, when perceived by birds, cigarette butts were similar in appearance to the nest lining and showed sharp contrast with the eggs. We suggest that cigarette butts form an opportunistic structural component of the song thrush nest. It remains to be determined whether human-made objects in song thrush nests serve anti-predator or an olfactory signalling function. This study illustrates the application of avian perceptual modelling to test signalling based hypotheses for the extended phenotype of birds, including nest architecture.

INTRODUCTION

Birds are well known to be proficient nest builders and the most important function of nests is to provide protection for developing offspring (Collias 1964). The need for protection and thermoregulation is thought to be a critical factor driving selection on nest location, and the shape, composition, and size of nests (Hansell 2000). Selection should thus favour nest building behaviour that provides optimal breeding conditions in particular habitats (Mertens 1977).

The use of specific nesting materials can increase concealment or crypsis (Solis & de Lope 1995), but in some cases they may also serve as anti-predatory material to keep away predators (e.g. snake sloughs and carnivore scat; Strecker 1926; Schuetz 2005). Other functions include protection against ectoparasite infestations through the incorporation of odorous leaves and moss (Clark & Mason 1988; Banbura *et al.* 1995; Lambrechts & Santos 2000), and the regulation of nest microclimate through the use of fine grasses, feathers, and mammalian fur (Bartholomew *et al.* 1976; Blem & Bleam 1994; Winkler 1993; Lombardo *et al.* 1995). Finally, nest building and the resulting size of the nest can also

be associated with courtship behaviour and serve as a sexually selected trait; in turn, signalling to conspecifics, including mates, about the quality and quantity of individual reproductive investment into the pair-bond and the breeding attempt is predicted to be beneficial in species with biparental care (Soler *et al.* 1998; Brouwer & Komdeur 2004).

These alternative, though not mutually exclusive hypotheses for the adaptive use of nest materials may be classed into either non-signalling or signalling functions. Non-signalling roles include the structural and physical functions of the materials, while the sensory appearance (e.g., odour, colour, texture) of the nest materials may contribute to a signalling function (Brouwer & Komdeur 2004). Birds normally incorporate a variety of plant and animal materials into the nest structures (Kessel 1957; Collias 1964; Briel & Moyle 1976; van Ripper 1977; Collias 1986; Nadkarni & Matelson 1989), and in some situations, birds also use human rubbish to build nests. It is unknown whether human-made objects function either as a structural element or play a signalling role.

A specific prediction of any conspecific hypothesis invoking signalling to mates about the content and the structure of the nest is that sensory cues of the particular nesting material be perceivable and discriminable by the intended receiver. We tested whether cigarette butts form a conspecifically conspicuous element of material in the nests of introduced songbird, the biparental song thrush (*Turdus philomelos*) in New Zealand. We modelled the perceptual ability of thrushes to discriminate cigarette butts incorporated into the nest's inner lining from the colouration of the eggs and the rest of the interior nest lining. Such a perceptual approach is a first step in testing the assumptions of whether human objects play a signalling role in song thrush nests. Human-based estimates of conspicuousness, crypsis, and mimicry may be poorly applicable to foreign objects in bird nests because the avian visual system differs from visual systems of humans and other mammals in relation to the number of photoreceptors, the types of photoreceptors and sensitivity of photoreceptors (Hunt *et al*. 2009).

METHODS
Field observations
We located song thrush nests in the Auckland Botanic Gardens (37° 0′ 46.8″ S, 174° 54′ 27″ E) and Meola Reef Reserve (36° 51′ 3.3″ S, 174° 42′ 38.15″ E), New Zealand during the 2007–2008 austral breeding season. Both are urban sites. We inspected the contents of active song thrush nests and recorded the proportion of nests that had cigarette butts incorporated into the lining of the nest interior.
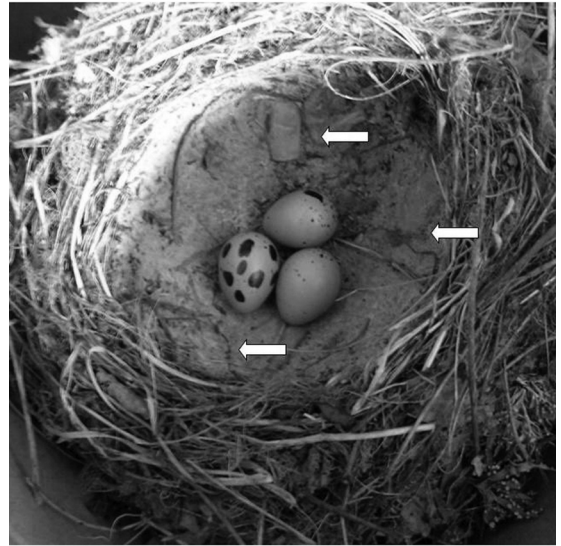

Fig. 1. Song thrush nest and eggs (1 manipulated and 2 control) from which nest background and cigarette reflectance measurements were taken. White arrows indicate the positions of the three cigarette butts incorporated into interior nest matrix. Photo credit: Mark Hauber.

Song thrush nests are very suitable for rapid visual inspection, especially in comparison with the congeneric European blackbird (*T. merula*), because the interior is lined with a relatively uniform layer of mud and plant fibres, making the presence of foreign material in the lining obvious (Fig. 1).

An additional song thrush nest was located in the Rose Garden on the grounds of the University of Auckland, City Campus, Auckland, New Zealand (36° 51′ 2″ S, 174° 46′ 4″ E) in Nov 2007. The nest was the subject of an egg painting experiment for a separate study, resulting in an egg painted with a Sharpie™ felt tip black pen. Following completion of the study, the nest was collected for spectrophotomeric analysis in the lab. The nest cup interior contained 3 pieces of cigarette butts incorporated into the interior nest lining (Fig. 1). The nest was stored in a dark place at room temperature until analysis.

Reflectance spectra measurements
Reflectance measurements of eggs, the mud lining, and cigarette butts were taken using an Ocean Optics USB2000 Miniature Fiber Optic Spectrometer, illuminated by a DT mini-lamp and OOIBase32TM operating 136 software (Ocean Optics, Inc., Dunedin, FL, USA). We used a probe with a custom built cap lined with black velvet so that it was maintained at a 90° angle and omitted all outside light sources. Three measurements were taken at randomly chosen locations on the nest background.

Table 1. Mean values for ΔS (or the just noticeable differences: JND for chromatic contrasts) ± standard error.

JND	Nest	Egg
Cigarette	1.29 ± 0.29	1.96 ± 0.17
Sharpie Pen	4.72 ± 0.51	1.99 ± 0.11
Nest	–	3.19 ± 0.23

Table 2. Mean values for ΔfQ (or the just noticeable differences: JND for achromatic contrasts) ± standard error.

JND	Nest	Egg
Cigarette	1.18 ± 0.55	2.59 ± 0.45
Sharpie Pen	3.17 ± 1.31	0.81 ± 0.19
Nest	–	3.77 ± 0.67

A single measurement (*ca.* 2 mm diameter) was taken on a random location along the length of each cigarette for a total of 3 cigarette measurements, and 3 measurements were taken on random equatorial locations on each of the 3 eggs found in the nest. Measurements were taken at 0.48 nm intervals in the avian-visible, ultra-violet (UV) inclusive range of 300–700 nm. White and dark standard reflection calibration measurements were taken between each set of 3 reflectance measurements using the Ocean Optics WS-1 diffuse reflectance standard and a custom-built black box, respectively.

Perceptual modelling
To model the avian visual perception of the cigarettes and estimate the ability of a song thrush to discriminate a cigarette from the nest background, we employed the approach developed by Vorobyev & Osorio (1998) for tetrachromatic vision of UV sensitive birds (300–700 nm) by using Avicol v2 software (Gomez 2007; Doutrelant *et al.* 2008). Due to the lack of published data on the song thrush cone sensitivity, sensitivity data used in the analysis were those for a close relative, the European blackbird (Cassey *et al.* 2008). Sensitivity data were extracted from published information in Hart *et al.* (2000) using VistaMetrix v1.3 (SkillCrest, LLC., available from http://www.skillcrest.com/) within the visual range between 330–700 nm. As the Avicol software requires a full set of sensitivity data between 300–700 nm, photoreceptor absorbance between 300–330 nm was set as zero. The song thrush is an open-cup nesting species, and so to simulate natural nest illumination, open nest irradiance spectra were extracted from the published information in Avilés *et al.* (2008) in the 300–700 nm range.

The Weber fraction for the long-wave sensitive cone (LWS) used in the model was set at 0.1 (Vorobyev *et al.* 1998) and the signal to noise ratio used in the calculations was independent of the signal and was based on neural noise only ($e_i = \omega / \sqrt{\eta_i}$; Vorobyev & Osorio 1998). A ratio of UVS 1: SWS 2: MWS 3: LWS 3 for the density of the 4 avian photoreceptor classes was assumed (see Stuart-Fox *et al.* 2008; Vorobyev & Osorio 1998). We assumed the achromatic contrast was based on the sum of the spectra of MWS and LWS cones, because the sensitivities of these photoreceptors are similar to that of rod and principle double cone cells (Hart *et al.* 1998; 2000).

The Avicol software extracts the bird's ability to distinguish, for instance, a cigarette butt from the nest background as the perceptual distance between the two spectra (ΔS) or the 'just noticeable difference' (JND). A JND greater than 1.0 indicates that a bird is able to distinguish the colour of the cigarette from the colour of the nest interior (Osorio & Vorobyev 1996). The software also estimates the ability of a bird to distinguish the brightness of a cigarette butt from that of the nest background as a JND for the achromatic contrast (ΔfQ).

Achromatic mechanisms become increasingly important for discrimination in dimmer light conditions while chromatic mechanisms are more important in brighter environments (Vorobyev & Osorio 1998). Because the song thrush nest is an open cup and is more similar to a bright light environment, we would predict that the ability of birds to distinguish cigarette butts from the nest background would be mostly influenced by chromatic mechanisms. The average JNDs for pair-wise comparisons were therefore calculated by pairing egg colour spectra randomly for each cigarette, black-pen painted egg surface and nest background, to remove statistical independence violations. This was then repeated for nest background spectra.

RESULTS
We found cigarette butts in 1 of 32 nests song thrush nests at the Auckland Botanic Gardens, and in 7 of 34 nests at Meola Reef Reserve (Fisher's exact test: P = 0.05). In total, 12% of song thrush nests had cigarette butts visible in the nest lining.

The cigarette and nest interior both appear to have a similar spectral curvature, as compared to the song thrush egg and the marker pen, indicating that the chromatic components of each object are similar (Fig. 2). In comparison, the cigarette butt has a greater total reflectance indicating that it is brighter than the nest interior background.
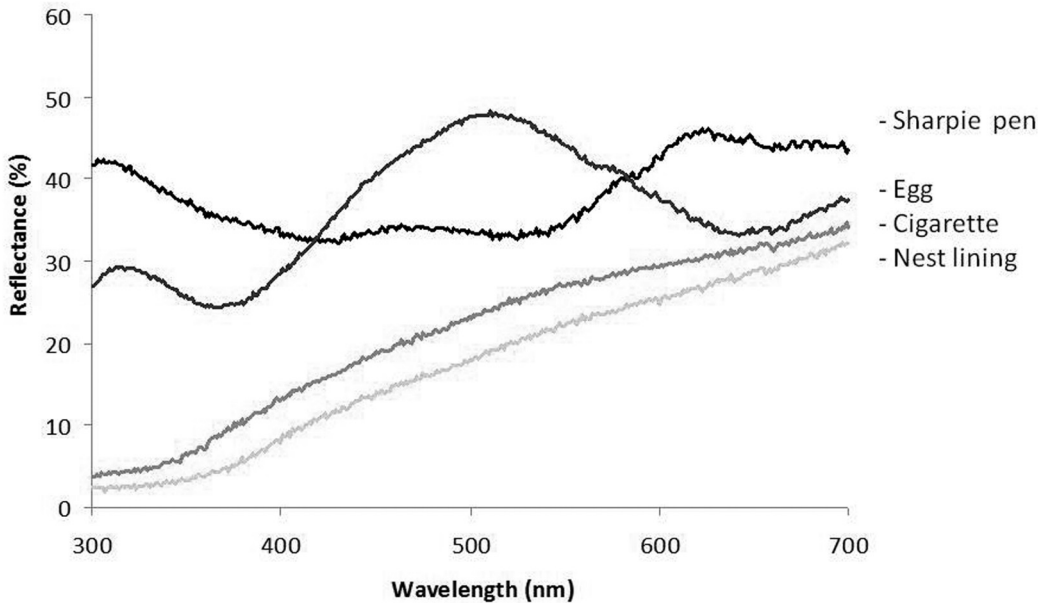
Fig. 2. Representative reflectance spectra of the colours of the cigarette butts, nest background, sharpie marker pen and song thrush egg background. Shown are the means from 3 reflectance measurements for cigarette butt, nest background and sharpie pen, and 9 reflectance measurements for song thrush eggs.

The chromatic components of cigarette butt and nest interior were found to be perceived as similar by the *Turdus* visual system (Table 1). The cigarette butt was found to be less conspicuous against the nest interior than the song thrush eggs for both the chromatic and achromatic components of colour (Tables 1, 2). The mean and standard errors suggest that cigarette butts can be perceived by birds as consistently different from egg surfaces but not from the nest lining.

DISCUSSION
We found no evidence that cigarette butts are visually conspicuous against the interior nest lining of a song thrush nest included in this study. Clearly, more work is needed to increase sample sizes and the types of human-made objects that are included in song thrush nest linings. Nonetheless, we suggest that it is unlikely that thrushes selected cigarette butts to incorporate into their nests to function as a signal to mates or other conspecifics (c.f. Brouwer & Komdeur 2004). Rather, it appears that thrushes are simply using discarded cigarette butts as a convenient construction material.

Although the number of nests we found with cigarette butts was small, we detected a greater proportion of nests with cigarette butts in the Meola Reef Reserve than at the Auckland Botanic Gardens, despite the greater public density in Gardens during

daytime hours (*pers. obs.*). However, institutional policy of the Auckland Botanic Gardens prohibits smoking on the grounds, while the Meola Reef Reserve does not, and also the latter has an additional source of particulate garbage from washed up items along the nearby ocean shore. Thus, the difference in availability of cigarette butts may play a role in the rates at which such items are included into nests across different sites.

In our approach we have modelled colour differences as perceived by a blackbird visual system but inferred our results in relation to song thrush perceptual ability. We consider this appropriate because of the close phylogenetic relationship and similar behaviours of blackbirds and song thrushes in New Zealand. As with most Northern hemisphere oscines, both of these *Turdus* species are UV sensitive (Ödeen & Håstad 2003), and the known photoreceptor sensitivities of blackbirds are also very similar to those of an even more distantly related passerine species, the blue tit (*Cyanistes caeruleus*; Hart *et al.* 2000).

It is likely that cigarette butts are more conspicuous in nests composed of different plant or other naturally occurring materials and it is unknown how frequently other species in New Zealand incorporate cigarette butts into their nest lining. Further investigation could possibly include assessment of possible roles (reviewed in Møller 1984; Winkler 1993; Lombardo *et al.* 1995)

of human-made objects, include cigarette butts, in regulating nest microclimate, olfactory signalling and deterring odour-driven predators. Overall, whether some anthropogenic waste is beneficial or harmful also remains to be evaluated in future work quantifying the success of clutches and broods in nests that incorporate human garbage.

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