Electronic Supplementary Material ESM

Supplementary methods

Monitoring nest activity

We tracked visits of male blue tits at nest-boxes using transponders (Trovan ID 100 Implantable Transponder; length: 11.5 mm; diameter: 2.12 mm; mass: 0.09 g). Each identification system works by recording the date and time when a bird with a transponder enters and leaves the magnetic field surrounding the antenna. To allow for habituation, a dummy antenna (made of electric cable) had been applied around the entrance hole outside the focal nest-boxes several weeks before we made the actual recordings. In 2008, on March 28th (while nest building had just started), the real antenna (single coil square antenna ANT614 OEM: 85 x 55 x 2 mm) was mounted and connected to the battery-driven OEM board/data logger unit (LID665 OEM, EID Aalten B.V., Aalten, The Netherlands). We captured 17 birds (7 males, 10 females) from 10 pairs in their territory with mistnets during nest building. We then collected data on 10 birds (4 males, 6 females) at 6 nest-boxes simultaneously with 6 units (5 birds were not re-observed or lost their transponder and one pair could not be followed). The transponders were either glued to two plastic leg bands (XF size, Ecotone via Nature Anim' Environnement, Vertou, France) with epoxy cement allowing the transponder to move freely with the leg bands (10 birds) or gently implanted in the abdominal cavity via peritoneal injection (7 birds). The mass of the leg device (ca. 0.17 g) increases the mass of an average blue tit by 1.5%. This method has proven to be efficient to monitor chick feeding frequency in nest cavity breeding species such as marsh tits (Nilsson 2003) and blue tits (Johnsen et al. 2005; Råberg et al. 2000; Sanz & Garcia-Navas 2009).
In 2009, we equipped 132 birds (66 males, 66 females) with transponders glued on leg bands. Fifty seven (38 males, 19 females) were captured at night while sleeping in nest-boxes in January and February. We captured the remaining birds with misnets during nest building (21 males, 37 females), egg laying (5 males, 8 females) or within the first days of incubation (2 males, 2 females). From March 24\textsuperscript{th}, we monitored 52 nest-boxes, sequentially with 12 units. In some cases, the birds did not lay eggs or their status (territory owner vs. visitor) could not be ascertained. We thus ended up with data from 44 nest-boxes and 80 monitored (resident) birds (39 males, 41 females). We excluded all data collected on the day of capture.

Recording of nest visits lasted from March 31\textsuperscript{st} to May 1\textsuperscript{st} 2008 and from March 31\textsuperscript{st} to May 13\textsuperscript{th} 2009. The nests were on average monitored for 22.5 ± 2.1 (mean ± SD) days in 2008 and 6.4 ± 2.6 days in 2009 during the laying and incubation phases. The activity at nest-boxes ranged from 6:30am to 8:30pm CEST, and never exceeded 14 consecutive hours at a given nest-box. For each monitored nest-box and for males and females separately, we thus divided the total number of visits per day by 14 (hours) to obtain the daily within-pair nest visit frequencies per hour, except for the truncated days (e.g. system installation) for which we adjusted the divider to account for the monitored hours only. Data+1 were Box-Cox-transformed for the statistical analysis.

Monitoring egg visibility in nests

During the laying phase in 2009, we checked everyday if we could see the clutch or if it was covered with nesting material or by a blue tit. The eggs could be uncovered (all eggs were visible), slightly covered (parts of the eggs were still visible) or totally covered (all eggs were invisible). In total, we did 396 independent observations in 68 nests.
Using previously collected data, we also assessed whether the bird sat on the eggs during the incubation phase was systematically a female. In 1998 and 1999, as part of different studies in which the sexes within pairs needed to be discriminated for behavioural observations (unpublished), in 61 different nest-boxes the incubating bird while remaining still on the eggs was marked with picric acid that was gently applied with a brush on one of its cheeks. The birds were later captured for routine measurements and for 12 pairs, the presence or absence of marks in relation to sex was reported.

Measures of blue tit eggshell coloration

Colour was measured with an Ocean Optics USB4000 with xenon lamp PX2 spectrophotometer (range: 300-700 nm) and 200-microm fibre optic probe. All measurements were taken perpendicular to the eggshell surface using the probe mount with a back rubber cap to exclude ambient light. The probe was held at a fixed distance of 2 mm from the eggshell surface. We generated reflectance data relative to a white standard (WS1 ocean optics) and to the dark. For each egg and colour variable (white eggshell background or brown spots), we computed the mean of five reflectance spectra (figure S1). The repeated measurements were taken each at a different point of the eggshell and led significant repeatability values $R$ for the calculated contrasts (see below): $0.11 > R > 0.68$, all $P < 0.05$ (Lessells & Boag 1987).

Estimation of blue tit capacity to distinguish eggshell coloration

With Avicol software v3 (freely available on request at dodogomez@yahoo.fr, Gomez 2006), we ran various physiological models (Vorobyev et al. 1998) which all accounted for nest-box luminosity and blue tit spectral sensitivity. Nest-box luminosity was calculating by extracting
raw data with Windig v2.5 (Lovy 1994-1996) from the irradiance spectrum of figure 3a in Hunt et al. (2003). Thus the total irradiance from 300 to 700 nm equals 34 µmol, which is equivalent to forest shade values ranging from 8 to 46 µmol (Endler 1993). To model blue tit spectral sensitivity, we computed a model for a tetrachromatic vision with cone photoreceptor proportions of 1, 1.92, 2.68 and 2.7 (Hart et al. 2000; Håstad et al. 2005).

We ran two models: a model with a neural and quantum photoreceptor noise and a model with a photoreceptor noise based only on neural noise. The model with a neural and quantum photoreceptor noise corresponds to improvement to the original model (Vorobyev & Osorio 1998) and was suggested by Osorio et al. (2004) to account for the fact that light intensity may limit visual performance in dim-light conditions. This correction considerably lowers contrast values compared to the original model, since it models a visual system which performance decreases in dim-light conditions.

Yet several physiological mechanisms have been revealed – namely temporal or spatial summations (Warrant 1999) or simultaneous contributions of cones (limited by dim-light conditions) and rods (particularly adapted to dim-light conditions) (Reitner et al. 1991; Vorobyev & Osorio 1998) – that efficiently compensate for restricted light and enhance visual performance. Such a visual system would largely outperform the performance as modelled by the neural and quantum noise.

We thus chose to run a model with a photoreceptor noise based only on neural noise, i.e. where light intensity was not limiting visual performance. Although this model did not accurately modelled any particular (unknown) mechanisms likely at stake in dim-light conditions, it was interesting to model outputs not limited by light intensity as would be an efficient visual system endowed with compensative mechanisms operating in restricted light conditions. Such a model has been successfully used in comparable light conditions (e.g. forest shade environment in Gomez & Théry 2007).
We acknowledge that both options were likely incomplete models of blue tit vision in nest-box environments but we decided to present both for comparative purposes and to discuss the eventual need for further developments in vision modelling.

Estimation of blue tit capacity to discriminate colour differences between eggs of different females

For the contrasts of white eggshell background within clutches, we compared all eggs with each others within each clutch (479 eggs from 42 clutches, i.e. 2562 comparisons). For the contrasts of white eggshell background between clutches, we limited the number of comparisons in selecting randomly (with CopyRandom software, NJ Tralles 2006; freely available on request) only two eggs per clutch (84 eggs from 42 clutches, i.e. 3444 comparisons). For brown spots, we could only calculate their contrasts between clutches since we only measured one egg per clutch, except for one clutch from which we randomly selected a single egg (30 eggs from 30 clutches, i.e. 435 comparisons).

In the linear and linear mixed-effect models, we used Box-Cox transformation whenever necessary to achieve normal distribution. We tested whether between-clutch variation of white eggshell background contrasted against nest background exceeded its within-clutch variation with repeatability estimates $R \pm 1$ SE following Lessells & Boag (1987) and Becker (1984).
Figure S1. Spectra of blue tits’ nest background (4 nests with five reflectance spectra per nest), white eggshell background (479 eggs from 42 clutches) and brown spots (31 eggs from 30 clutches) plotted from 300 to 700 nm. Shown are means ± 1 SD.


Gomez, D. 2006 AVICOL. A program to analyse spectrometric data.


Supplementary results

As expected, female nest activity was higher than male activity (table S1). We recorded 16 extra-pair nest visits from 3 neighbouring females (1 in 2008, 2 in 2009).
Table S1. Descriptive statistics of within-pair nest visit frequencies per hour across days.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± 1 SD</th>
<th>Range</th>
<th>Monitored birds</th>
<th>Monitored days</th>
<th>Sample size (days) per bird : number of birds</th>
</tr>
</thead>
<tbody>
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<td>Egg laying</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>male</td>
<td>0.6 ± 1.4</td>
<td>0.0-5.5</td>
<td>19</td>
<td>92</td>
<td>1:3 / 2:2 / 3:2 / 4:4 / 5:1 / 6:2 / 8:2 / 9:2 / 12:1</td>
</tr>
<tr>
<td>female</td>
<td>7.4 ± 12.8</td>
<td>0.3-54.8</td>
<td>21</td>
<td>112</td>
<td>1:3 / 2:2 / 3:2 / 4:4 / 5:1 / 6:2 / 8:3 / 9:2 / 12:2</td>
</tr>
<tr>
<td>Incubation</td>
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*Grand means (i.e. means of within-individual means).

*One female had an extremely high activity level at her nest on De11. Excluding her gives the following mean ± 1 SD = 5.1 ± 6.9, range = 0.3-26.7, n = 20.
Figure S2. Percentages of colour (a,c) and brightness (b,d) contrasts above (white bars) or below (grey bars) 1 just noticeable difference (JND). Photoreceptor noise is either independent (a,b) or dependent of light intensity (c,d). Shown are the contrasts of white eggshell background against nest background (shell/nest), brown eggshell spots against nest background (spot/nest), brown spots against white eggshell (spot/shell), white eggshell between clutches (shell/shell<sub>BC</sub>), within clutches (shell/shell<sub>WC</sub>) and brown spots between clutches (spot/spot<sub>BC</sub>).