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ORIGINAL RESEARCH ARTICLE

Lattice fence and hedge barriers around an apiary increase honey bee flight height and decrease stings to people nearby

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Summary

Urban beekeeping is becoming more popular in the UK. One of the challenges faced by urban beekeepers is finding a suitable apiary location. Honey bees are often perceived as a nuisance, mainly due to their stinging behaviour. Here, we experimentally test the assumption that barriers around an apiary such as walls or fences, force the bees to fly above human height, thereby reducing collisions with people and, consequently, stinging. The experiment was conducted in two apiaries using two common types of barrier: a lattice fence (trellis) and hedge. Barriers were 2 m high, which is taller than > 99% of humans and is also the maximum height allowed by UK planning regulations for garden fences or walls. We found that barriers were effective at both raising the mean honey bee flight height and reducing stinging. However, the effects were only seen when the barrier had been in place for a few days, not immediately after the barrier was put in place. Although this raises interesting questions regarding honey bee navigation and memory, it is not a problem for beekeepers, as any barrier placed around an apiary will be permanent. The effect of the barriers on raising bee flight height to a mean of *c.* 2.2-2.5 m was somewhat weak and inconsistent, probably because the bees flew high, mean of *c.* 1.6-2.0 m, even in the absence of a barrier. As barriers can also reduce wind exposure, improve security and are inexpensive, we recommend their use around urban apiaries in places such as private gardens or allotments, where nuisance to humans is likely to be a problem.

Las vallas de celosía y las barreras de seto en torno a un colmenar incrementan la altura de vuelo de las abejas y disminuyen las picaduras en personas de la proximidad

Resumen

La apicultura urbana es cada vez más popular en el Reino Unido. Uno de los retos a los que enfrentan los apicultores urbanos es encontrar un lugar adecuado para los apiarios. Las abejas de la miel son a menudo percibidas como una molestia, debido principalmente a su comportamiento defensivo de picar. En este sentido, hemos puesto a prueba experimentalmente la hipótesis de que ciertas barreras alrededor de un colmenar, como paredes o cercas, obligan a las abejas a volar por encima de la altura humana, lo que reduce las colisiones con la gente y, en consecuencia, las picaduras. El experimento se realizó en dos apiarios utilizando dos tipos comunes de barrera: una valla de celosía (enrejado) y otra de seto. Las barreras fueron de 2 m de altura, es decir más alto que el 99 % de los seres humanos y es también la altura máxima permitida por la normativa urbanística del Reino Unido para vallas de jardín o paredes. Encontramos que las barreras fueron efectivas en cuanto al aumento de la altura media de vuelo de la abeja de la miel y la reducción de las picaduras. Sin embargo, los efectos sólo se observaron cuando la barrera había estado en el lugar durante unos días, no inmediatamente después de que la barrera se pusiera. Aunque esto plantea preguntas interesantes respecto al vuelo de la abeja de la miel y de su memoria, no es un problema para los apicultores, ya que cualquier barrera colocada alrededor de un apiario sería permanente. El efecto de las barreras en el aumento de la altura de vuelo de la abeja a una media de alrededor de 2,2 a 2,5 m fue algo débil e inconsistente, probablemente porque las abejas volaron alto, con una media de alrededor de 1,6 a 2,0 m, incluso en ausencia de barrera. Como las barreras pueden reducir también la exposición al viento, mejorar la seguridad y son de bajo costo, se recomienda su uso alrededor de los apiarios urbanos en lugares como jardines o huertos privados, en los que es probable que sea un problema molesto para los seres humanos .

Key words: Honey bee, beekeeping, apiary design, urban areas, bee navigation

Introduction

Although honey bee (*Apis mellifera*) hives are often kept in the countryside away from people and housing, many are also kept in urban and suburban areas. Indeed, urban beekeeping is becoming more popular (Benjamin and McCallum, 2011). For example, in London UK, the number of registered colonies doubled to more than 3,500 over the last 5 years (2008-13) and the number of beekeepers tripled (Alton and Ratnieks, 2013). This is an underestimate, since the registration is non-mandatory. One challenge to urban beekeeping is finding suitable apiary locations. Numerous general criteria exist for choosing a good apiary location, including proximity to rich nectar sources, vehicle access, shelter from strong wind, sunlight, good air circulation to avoid frost pockets, and water drainage (Morse, 1996; Cramp, 2008). However, for an urban beekeeper, perhaps the most important is seclusion from fellow humans (Burgett *et al.*, 1978).

Honey bees are often perceived as dangerous due to their stinging behaviour. Being stung by a honey bee worker is painful (Schmidt, 1990), but the main danger is to the small proportion of people (0.15 to 5.0%) who are allergic to hymenopteran venom, which can lead to anaphylaxis and in rare instances death (Schmidt, 1986; Neugut *et al.*, 2001). However, the risk is exceedingly small, as one is twice more likely to die from a lightning strike than from a bee sting (Schmidt, 1986). In the UK (England & Wales) in 2011, only two deaths were caused by "contact with hornets, wasps or bees", three times fewer than were caused by a "bite or strike by dog" (Office for National Statistics, 2012). Many people believe they are allergic to honey bee stings, when in fact they are not (Charpin *et al.*, 1992), probably because the normal reaction of a non-allergic person is often considerable, involving immediate pain, followed by local swelling and itching lasting a day or more (Vetter and Visscher, 1998). In any event, a sting from a worker honey bee is an unpleasant experience and one to be avoided.

Barriers, such as fences, hedges or buildings, surrounding an apiary are often recommended in order to force the bees to fly above human height (Caron, 1976a in Burgett *et al.*, 1978; Cramp, 2008), thereby lessening the chance that foraging bees leaving or returning to their hives will bump into humans. As colliding bees may become entangled in hair or clothing, and often result in ineffective attempts to brush then off, this can easily lead to stinging. Here, we perform the first experimental test of this recommendation, using two types of barrier: a wooden lattice fence (trellis) and a hedge.

Material and methods

Experimental setup and procedure

The study was conducted using experimental apiaries set up at two locations: Wakehurst Place, West Sussex, UK (lat: 51.067163, long: -0.090604484) and Plumpton College, East Sussex, UK (lat: 50.911375, long: -0.081055820). Four strong honey bee colonies were used in each apiary.

The apiaries were located with a wooden shed and a brick wall on two sides (Wakehurst) or a large metal barn on one side (Plumpton), with the hives 50 cm from the building and facing away (Figs. 1,2). On other sides temporary barriers of either lattice fence or hedge were positioned 1 m from the hives, and could be swapped or removed within a few minutes as needed during the experiment. This was referred to as the "current" treatment in the analyses. Honey bee flight heights were recorded at four distances on the far side of the barrier at 1, 3, 6 and 16 m at Wakehurst. At Plumpton 8 m was used instead of 6 m due to the land layout, as there was a ditch at 6 m (Fig. 1B). Flight heights were recorded at each of 12 barrier × distance combinations on each day, and repeated on six non-consecutive days in the periods August to October, 2011 (Wakehurst) and July to September, 2012 (Plumpton). In addition, each of the three barrier treatments (lattice, hedge or no barrier) was left in place for multiple days (mean 9.1, range 2-23), before two of the six experiment days in each dataset; this was included as the "pre-treatment" in the analyses. At Wakehurst, due to the layout of the garden in which the apiary was located, only one direction could be investigated, but in the Plumpton apiary, the same procedure was replicated in two directions at 90° to each other, but the hives were not rotated, such that their entrances were always facing direction 1 (Fig. 1B). Thus, in total, three comparable datasets were obtained from two apiaries.

Barrier design

The lattice fence barrier (AVS Fencing Supplies Ltd; UK) was made of 1.83 × 1.83 m panels consisting of 11 horizontal and 11 vertical wooden planks 3.6 cm wide spaced at equal intervals and resulting in 100 14.3 × 14.3 cm empty gaps per panel, or 61.4% gap space.

The hedge barrier was made of large freshly-cut birch (*Betula* sp.) branches with leaves at the Wakehurst apiary and young potted Leyland cypress trees (*Cupressus* × *leylandii*) at the Plumpton apiary. The amount of empty space was comparable between the two types of hedge and to that in the lattice fence.

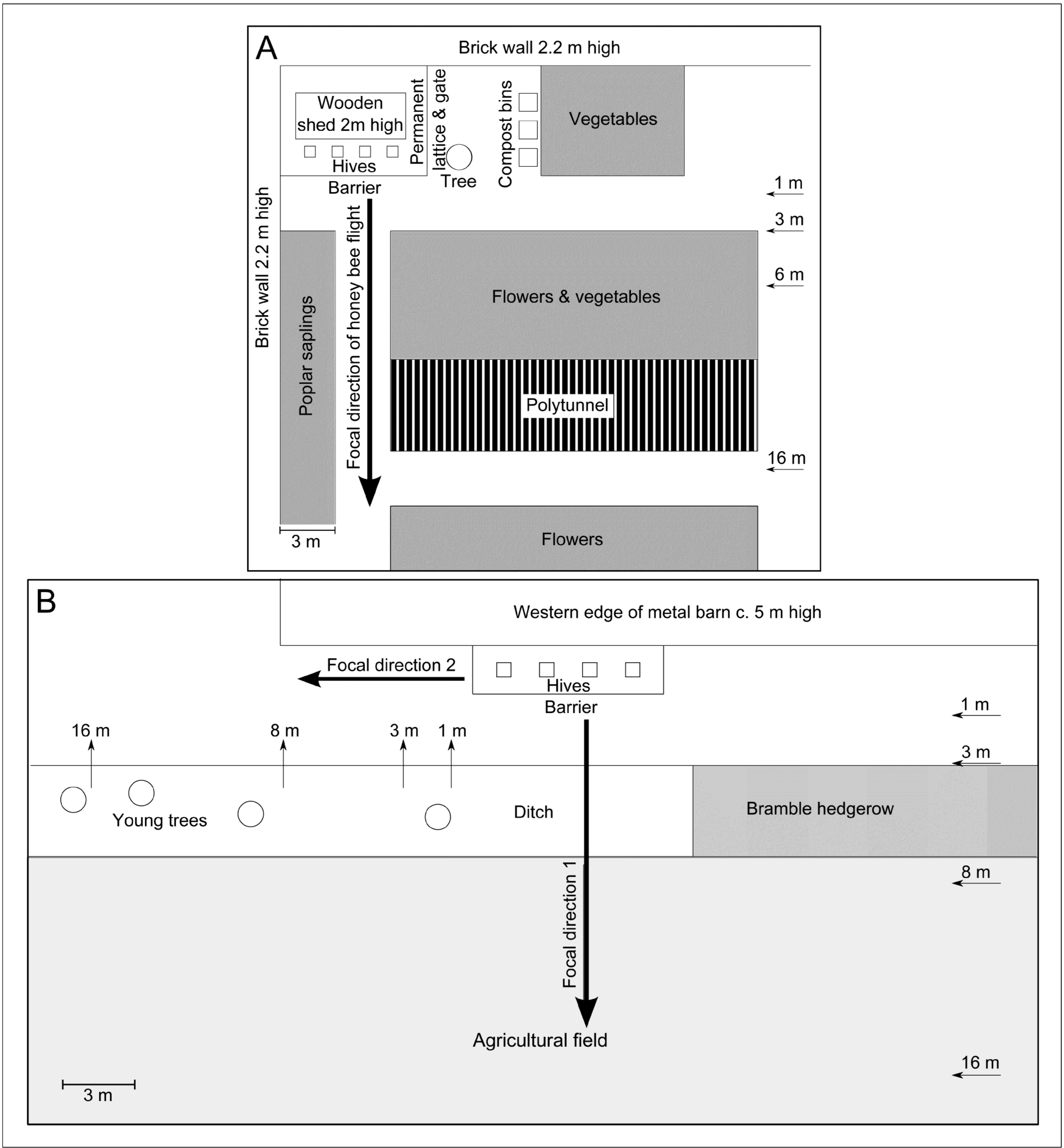

Fig. 1. Layout of the apiary and surrounding land at: ***A.*** Wakehurst Place; and ***B.*** Plumpton College. Small arrows mark the positions of the video camera at four distances perpendicular to the focal directions of honey bee flight.

All barriers were positioned 1 m in front of and perpendicular to the hive entrances (Figs. 1,2) and were 2 m high. To achieve this height the lattice panels were raised by 17 cm from the ground and hedge plants and branches were trimmed. In the Wakehurst apiary and in direction 1 in the Plumpton apiary, the length of the barrier was 8 m, while in direction 2 at Plumpton the length was 2 m (Fig. 1).

Measuring flight heights

The flight paths of honey bees were recorded at each distance using a Sony HDR-CX130E video camera. Recordings were made sequentially at each distance and barrier treatment against a white-painted plywood screen (1.6 m wide × 3.5 m high), positioned perpendicular at the far end of the barrier and parallel to the focal direction of honey bee flight

Fig. 2. Experimental apiary setup showing white-painted plywood screens next to the lattice fence barrier (***A.*** Wakehurst) and the hedge (***B.*** Plumpton).

(Figs. 1,2). The video camera was on a tripod at a height of 1.7 m and 20 m from the white background to reduce parallax error. The video was played back frame by frame on using QuickTime v. 7.7.3 on an Apple iMac computer with 19″ (16:9) screen. Flying bees could be seen clearly as black dots. The flight heights of 10 consecutive individual honey bees (both incoming and outgoing) at each of the 12 barrier × distance combinations on each experimental day were determined against a series of height markers on the white screen.

Measuring sting rate

Sting rate was measured by recording the number of stings to the experimenter (MG) during standardized trials, which involved simulating physical work by hitting a wooden post with a hammer for 2 min at 1 m from the barrier position. One trial was made at each of the 3 barrier treatments on each experimental day at each apiary.

Statistical analyses

Data were analysed using R v. 2.15.2 (R Development Core Team, 2012). The effects of current barrier, pre-treatment barrier, and distance from the barrier on honey bee flight height in each of the three full datasets (1 from the Wakehurst apiary, 2 from the Plumpton apiary) were analysed using generalized linear mixed-effect models (GLMM) with function *lme* (part of package *nlme* (Pinheiro *et al.*, 2012), using the maximum-likelihood estimation method. To account for putative non-independence of data within the same experimental day and to assess the need for GLMM, date was included as a random effect in the model before testing the fixed effects. We first compared the generalized least squares model (without the random effect) with the random intercept model and with the random intercept and slope model. In each dataset addition of the random intercept to the model significantly improved the fit to the data ($P < 0.05$). However, further addition of the random slope did not improve the fit significantly (see Results). The significance of the main effects (distance, current barrier and pre-treatment barrier) and their interactions were tested using the top-down model selection protocol and the likelihood ratio test, where the optimal model is arrived at by removing non-significant terms from the beyond optimal model (Zuur *et al.*, 2009).

The effects of current and pre-treatment barrier on the number of stings per trial were analysed using 2-way ANOVA, since the inclusion of date as random effect did not significantly improve the fit of the model. Post-hoc pairwise comparisons of levels within significant factors and interactions were carried out using Tukey's test (function *glht*, package *multcomp* (Hothorn *et al.*, 2008)). All values reported are means ± standard error, unless otherwise stated.

Results

Effects of current barrier, pre-treatment and distance on honey bee flight height

Wakehurst apiary

The addition of date as random intercept significantly improved the fit of model ($L = 6.653$, $df = 1$, $P = 0.001$). However, the addition of random slope did not ($L = 5.074$, $df = 5$, $P = 0.407$). Therefore, date was retained as random intercept in the model selection process.

The optimal model contained distance ($L = 8.183$, $df = 1$, $P = 0.004$) and pre-treatment barrier ($L = 8.805$, $df = 2$, $P = 0.012$) as significant main effect terms. Current barrier was not a significant factor ($L = 3.632$, $df = 2$, $P = 0.163$). Flight height was higher at 3 m from the barrier (2.32 ± 0.06 m) than at 6 m (2.05 ± 0.06 m; $P = 0.005$) or 16 m (2.02 ± 0.06 m; $P = 0.002$) (Fig. 3A). All other pairwise differences between distances were non-significant ($P > 0.05$). Flight heights were also higher on days when the bees were pre-treated with lattice fence (2.31 ± 0.05 m), compared to either hedge (2.03 ± 0.05 m; $P < 0.001$) or no barrier (2.09 ± 0.05 m; $P = 0.009$). Hedge and no barrier pre-treatments were not different from each other ($P = 0.682$) (Fig. 3D).

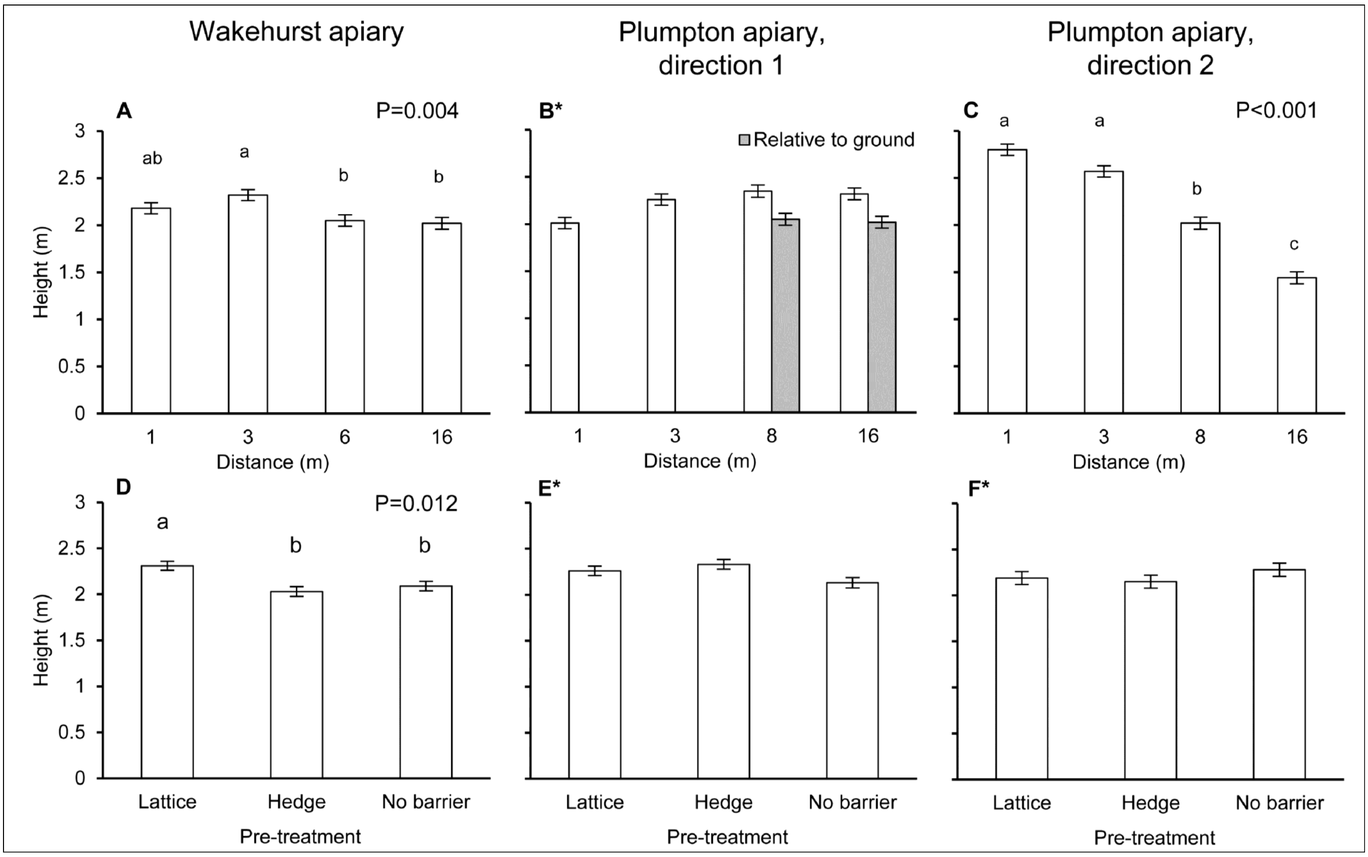

Fig. 3. Effect of distance (A-C) and pre-treatment barrier (D-F) on mean honey bee flight height in the Wakehurst apiary (A,D) and the Plumpton apiary at directions 1 (B,E) and 2 (C,F). Letters above bars represent results of Tukey's post-hoc pairwise comparison test. * In B, D & F, significance of main effects was not tested due to their involvement in significant interactions (see Results, Fig 4). Height measurements are relative to the ground level under the apiary. In B, the ground level at 8 m and 16 m was higher than at the apiary. Hence, the grey bars show bee fight height relative to the ground level at these distances. Bar heights are means ± standard error.

Plumpton apiary, direction 1

The addition of date as random intercept significantly improved the fit of the model (L = 7.002, df = 1, P = 0.008), however the addition of random slope did not (L = 6.674, df = 5, P = 0.246). Therefore, date was retained as random intercept in subsequent model selection process.

The optimal model contained distance * pre-treatment (L = 27.534, df = 2, P < 0.001) and current barrier * pre-treatment (L = 16.027, df = 4, P = 0.003) as significant interaction terms. The significance of main effect terms was not tested further, as all of these were involved in at least one of the above significant interactions.

The results of selected pairwise comparisons (including all those with significant differences) within the distance * pre-treatment interaction are shown in (Table 1). In summary, there was evidence of higher flight heights at 1 m distance from the barrier when the bees were pre-treated with either lattice (2.17 ± 0.10 m; P = 0.056) or hedge (2.28 ± 0.10 m; P < 0.01), compared to no barrier (1.62 ± 0.10 m) (Fig. 4B). There was also some evidence of a similar, but weaker effect at 3 m distance (2.00 ± 0.11 m) from the barrier position (1 m *vs.* 3 m no barrier comparison, P = 0.302) (Fig. 4B).

Table 1. Sub-set of the results of pairwise treatment comparisons, tested using post-hoc Tukey's test, exploring the distance * pre-treatment interaction in the Plumpton apiary direction 1. All significant (bold) and some non-significant pairs are shown; all pairs that are not shown are not significant at 5% confidence level.

Distance 1	Pre-treatment barrier 1	Distance 2	Pre-treatment barrier 2	P-value
1	Lattice	1	No barrier	0.056
1	Hedge	1	No barrier	**<0.01**
3	Lattice	1	No barrier	**<0.01**
3	Hedge	1	No barrier	**<0.01**
8	Lattice	1	No barrier	0.055
8	Hedge	1	No barrier	**<0.01**
16	Lattice	1	No barrier	**<0.01**
16	Hedge	1	No barrier	0.056
1	Lattice	3	No barrier	0.99
1	Hedge	3	No barrier	0.87
3	Lattice	3	No barrier	0.44
3	Hedge	3	No barrier	0.44
3	No barrier	1	No barrier	0.30
8	No barrier	1	No barrier	**<0.01**
16	No barrier	1	No barrier	**<0.01**
8	No barrier	3	No barrier	0.25
16	No barrier	3	No barrier	**0.03**

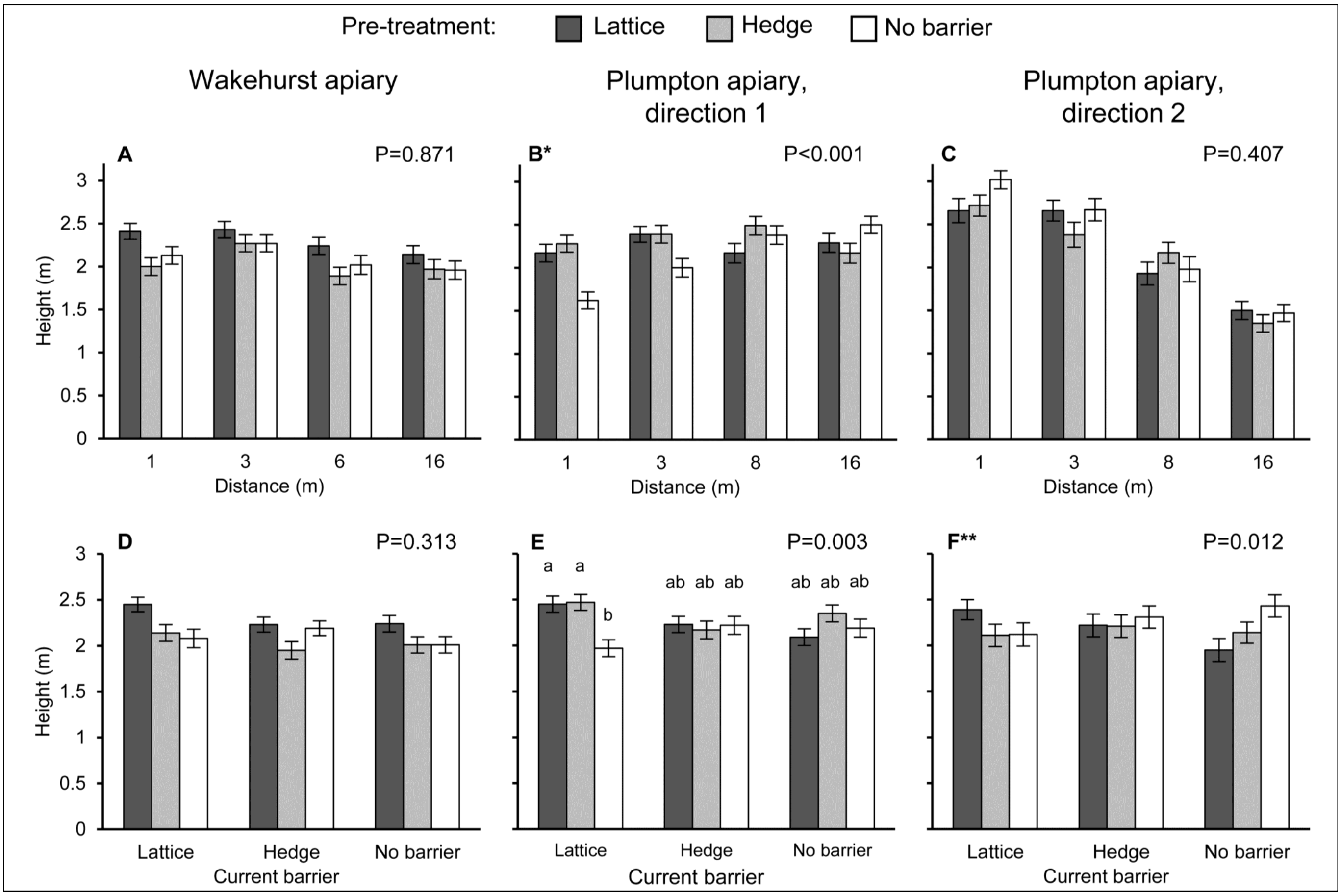

Fig. 4. The effects of distance * pre-treatment (A-C) and current barrier * pre-treatment (D-F) interactions on honey bee flight height in the Wakehurst apiary (A,D) and the Plumpton apiary direction 1 (B,E) and 2 (C,F). Letters above bars represent results of Tukey's post-hoc pairwise comparison test (* in B, the results are found in Table 1; ** in F, despite significant interaction, no pairwise comparisons between treatments were significant). Bar heights are means ± standard error.

Within the current barrier * pre-treatment interaction, flight height was greater after a quick change of barrier to lattice (current) and only when the bees were pre-treated to either lattice (2.45 ± 0.09 m; P = 0.049) or hedge (2.47 ± 0.09 m; P = 0.028), compared to the absence of a barrier (1.97 ± 0.09 m) (Fig. 4E). All other pairwise differences were non-significant (P > 0.05).

Plumpton apiary, direction 2

The addition of date as random intercept on the fit of model was non-significant (L = 3.808, df = 1, P = 0.051). However the addition of random slope had clearly non-significant effect (L = 3.272, df = 5, P = 0.658). The decision was taken to retain date as random intercept in subsequent model selection process, as its non-significance was marginal and it was used in the two previous analyses.

The optimal model contained distance as main effect (L = 195.376, df = 1, P < 0.001) and current barrier * pre-treatment interaction (L = 12.844, df = 4, P = 0.012) as significant terms. The significance of current barrier and pre-treatment main effects was not tested, as these were involved in the significant interaction.

Flight height tended to decrease with distance (Fig. 3C); although it was not significantly different between 1 m (2.80 ± 0.07 m) and 3 m (2.57 ± 0.08 m; P = 0.094), it was significantly different from both 8 m (2.08 ± 0.08 m) and 16 m (1.44 ± 0.06 m) (all P < 0.001).

Although the current barrier * pre-treatment interaction was significant in the final optimal model, no pairwise differences turned out significant (all P > 0.05). A qualitative look at the interaction (Fig. 4F) suggests that it is similar to the same interaction in direction 1 (which is significant in that dataset), as the flight height tended to be greater when the barrier was changed to lattice (2.39 ± 0.11 m) compared to no barrier (1.95 ± 0.13 m), but only when the bees were pre-treated to lattice (P = 0.188, lowes25.2 p-value of all pairwise comparisons).

Effects of current barrier and pre-treatment on the sting rate

In the Wakehurst apiary, 0 stings were recorded in a total of 18 2-minute trials. As a result, no further analyses were performed. In the Plumpton apiary, 10 stings in total were recorded using the same procedure. Since all trials were conducted at the same distance (1 m) from the barrier position, only current barrier and pre-treatment were included as fixed factors. The addition of date as random intercept (L = 1.245, df = 1, P = 0.265) and slope (L < 0.001, df = 5, P = 1.000)

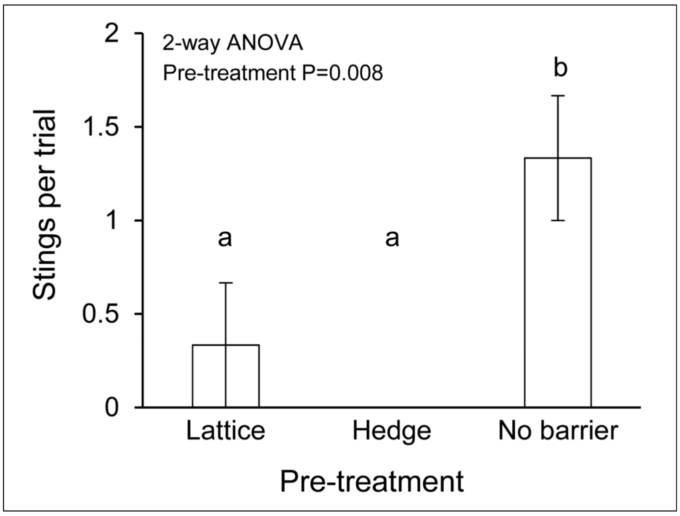

Fig. 5. The effects of pre-treatment barrier on the number of stings per trial. Letters above bars represent the results of Tukey's post-hoc pairwise comparison test. Bar heights are means ± standard error.

did not significantly improve the fit of the model. Hence, the data were analysed using 2-way ANOVA. Pre-treatment had a significant main effect on the number of stings per trial ($F_{2,9}$ = 8.667, P = 0.008), however current barrier did not ($F_{2,9}$ = 2.167, P = 0.171) and there was no significant interaction ($F_{4,9}$ = 1.667, P = 0.241). The number of stings per trial was lower when the bees were pre-treated to either lattice (0.33 ± 0.33; P = 0.036) or hedge (0.00 ± 0.00; P = 0.008) compared to no barrier (1.33 ± 0.33), a reduction of 87% (Fig. 5).

Discussion

The results show that a barrier always tended to raise honey bee flight height provided that it had been in place for a few days (i.e., was a pre-treatment). When the barrier treatment was changed, there was usually no immediate effect on flight height. The fact that a barrier needs to be in place for several days to be effective is not a problem for beekeepers, as barriers, whether hedges, lattice, or a building, are effectively permanent structures. However, it does lead to interesting questions in terms of honey bee memory and navigation. Returning foragers use special 'proximal' navigation in the hive vicinity, within a few metres, which is distinct from the 'distal' navigation used at long distances (Palikij *et al.*, 2012). Presumably, forager bees adopt a landing and take-off flight path that is appropriate to the barrier and use this path for some time even if the barrier is changed. This would indicate that they store multiple landmarks in their memory, so that changing one landmark, the presence or absence of a barrier, does not immediately change the flight path.

The effects on flight height were weak and inconsistent, probably because even in the absence of a barrier honey bees flew relatively high, mean *c.* 1.6 - 2.0 m. The effect of a 2 m barrier was, therefore, small, raising mean flight height to only *c.* 2.2 - 2.5 m. We deliberately used barriers of only 2 m as this is above the height of almost all humans (United States Census Bureau (2012) data show that 99.5-100% of men, depending on age group, and 100% of women are under 6 foot 6 inches tall (2m = 6 foot 6 ¾ inches)). In addition, this is a convenient height both in the purchase of fencing materials (which are often 6 foot or just under 2 m, and so can be made 2 m high by raising slightly off the ground when attaching to support posts) and in hedge trimming. Furthermore, British planning regulations require boundary fences or walls of over 2 m in height to have special planning permission (Planning Portal, n. d.). A beekeeper with an apiary in his or her garden can, therefore, erect a 2 m boundary fence without permission, except along road frontage where the maximum height is 1 m. Hedges are not restricted.

Our data indicate that barriers can potentially greatly reduce the chance of being stung in the vicinity of an apiary. This is of importance, as stinging is by far the most unwelcome thing that honey bees can do to people. Although experienced beekeepers are generally used to bee stings, members of the general public are not and a bee sting is generally a painful experience (Schmidt, 1990). Reduced stinging is probably a consequence of the greater proportion of forager bees flying above human height. However, the marked differences in sting rate between the two study apiaries suggest that the selection of non-aggressive colonies can also be of high importance. Colonies used in the Wakehurst apiary were loaned by a local semi-commercial bee-keeper, who had deliberately provided us with non-aggressive colonies for public safety reasons. In contrast, in the Plumpton apiary, colonies were randomly selected from those belonging to the Laboratory of Apiculture & Social Insects without regard to aggressiveness.

We think that these results would apply equally or possibly more strongly to solid barriers than to permeable ones, such as those used in this study. Casual observations made during the study and previous experience in using barriers around apiaries showed us that the vast majority of bees (> 95%) did not fly through the gaps in the barriers, but instead flew above them. This is similar to solid barriers, which do not allow any bees to fly through them. However, there are other considerations under which the use of an open barrier may be preferred. For example, depending on the layout of the apiary, open barriers may allow the hives to receive more direct sunshine and may promote better air circulation.

We conclude that barriers, such as those used in this study, are an effective way of reducing stings and contacts with bees in the vicinity of an apiary. We, therefore, recommend their use around apiaries, particularly in urban or suburban locations, such as private gardens or allotments, where nuisance to other people is likely to be a problem. Barriers are low cost and have other advantages, such as in reducing exposure to wind and improving security. Barriers may be of additional value when seeking permission to locate an apiary on borrowed land, such as on an allotment owned by a local council. The use of barriers could be considered an element of good practice, and one of several things that a beekeeper can do to reduce nuisance, and especially stinging, to other people.

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