*Title*: **BLACKAWTON BEES**

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SUMMARY

*Background:* 'Good' science education rarely involves actual science. And yet science is an amazing yet basic process of playing games and making puzzles in order to extend one's understanding of nature and human nature. Indeed, we have found that doing 'real' science (usually on bumblebees) in *public* spaces stimulates tremendous interest in children and adults in understanding the world and processes by which we make sense of it. Here we report the result of one such study on the vision of bumblebees that was not only performed outside the lab in a Norman church in the Southwest of England, but was itself devised by twenty five 8-to-10 year old children in the local primary school. *They* asked the questions, hypothesised the answers, designed the experiments to test these hypotheses and analysed the data. *They* also *drew* the figures (in coloured pencils) and wrote the paper (at a local village pub). So what you'll find here is a novel study (scientifically and conceptually) in *'kids speak'*. What you'll not find are references to past literature. While the historical context of any study is important, including references in this case would be disingenuous for two reasons: 1. Given the way scientific data is naturally reported, the relevant information is simply inaccessible to the literate ability of 8-to-10 year olds (without excessive direction which would defeat the project's underlying aesthetic); 2. The context for the kids in this study is not what scientists had done before, but what their own personal and shared curiousities of nature are (which at a more fundamental level is true for any scientific paper with integrity). This lack of historical context, however, does not change the data nor the merit of their discovery for the scientific and 'non-scientific' audience.

*Principle Finding:* "We discovered that bumblebees can use a combination of colour and spatial relationships in deciding which colour of flower to forage from. We also discovered that science is cool and fun because you get to do stuff that no one has ever done before."

## INTRODUCTION

Once upon a time …

People think that humans are the smartest of animals. And so most people don't think about other animals as being smart, or at least think that they are not as smart as humans. Knowing that others animals are as smart as us means we could appreciate them more, which could also help us to help them.

Scientists do experiment on monkeys, because they are close to man. But bees could actually be close to man too. We see bees in the natural habitat doing what they do. But you don't really see them doing human things … like solving human puzzles … like suduko. So it makes you wonder if they could solve a human puzzle. If they could solve it, it'd mean that they are really smart, smarter than we thought before. Which would mean that humans might have some link with bees. If bees are like us in some way, then understanding them could help us understand ourselves better.

To get ready to do experiments with bees we first talked about science being about playing games and making puzzles. We then got into groups and made up games for ourselves to play using random pieces of PE equipment. This gave us the experience of thinking of games and puzzles. Then we had to explain our games to other people. After talking about what it's like to create games and how games have rules to play, we then talked about seeing the world in different ways by wearing bug eyes, and mirrors and rolled up books. Then we watched the David Letterman videos of 'Stupid Dog Tricks', where dogs were trained to do funny things. Then we too had to learn to solve a puzzle that Beau and Mr Strudwick gave use (which takes artificial brain 10,000 trials to solve, but us only 4 times). Then we started asking questions about bees, and then more specific questions about seeing colour using the bee arena (See Figure 1).

We came up with lots of questions, but the one we decided upon was whether bees could learn to use the spatial relationships between colours to figure out which flowers had sugar water in them and which at salt water in them. It's interesting to ask this question because in their habitat there might be flowers that are bad for them, or some flowers that they might have already collected nectar from. Which would mean that it would be important for bees to learn which flowers to go to or to avoid by, which would need them to remember which the flowers were around it, which is like a puzzle.

To find this out we gave the bees a series of challenges to see if they could complete them or not, and then we tested them to see how they solved the puzzle and how they solved it. It was a difficult puzzle because the bees couldn't just learn to go to the colour of the flower. Instead they had to learn to go to one colour (blue) *if* it was surrounded by the opposite colour (yellow), but to also go to the opposite flower (yellow) *if* it was surrounded by blue. We also wanted to know if they would all solve it in the same way as each other. If they didn't, it would mean bees have personality (if a bee always goes to go to the blue flower every time, it tells us that that bee really likes blue).

## METHODS

*The bee arena:* The bee arena, which is made out of Plexiglas, has 5 panels. It is 1 metre high, 1 metre wide and 1 metre deep. Two of the side panels have three doors in them. It has a vertical light-box at the opposite end from the side that the bees enter the arena through a small hole. The light box is made out of aluminium with a Plexiglas screen in front of the six fluorescent lights. There is an aluminium cross in front of the Plexiglas screen. The cross has groves in the sides of it so that we can slide 4 black aluminium panels into the cross. Each panel has 16 cut out circular holes in 4 rows of 4 circles each. Each circle is 8cm in diameter. The holes are covered up by Plexiglas screen. In the centre of each circle there is a Plexiglas rod with a small hole in the middle in which we put sugar water or salt water or nothing. Behind each hole there are slits so that squares of coloured gel filters can be slotted in, making the light shining through each hole a colour. It's like putting a piece of coloured see-through paper on a light and the colour of the paper shines through.

*The bees:* The bees have black and yellow stripes with white bums. The type of bee was a *Bombus terrestris*. We got the beehive delivered from Koppert, UK.

*Training phase 1:* To teach the bees to go to the Plexigas rods as flowers, in every panel all the circles were white and all the rods had sugar water in. Once the labelled foragers learned that the flowers had a reward, which took 4 days, we marked the bees, and then setup the puzzle for them.

*Marking bees:* We let the foragers into the arena and then turned the lights off, which makes the bees stop flying (because they don't want to run into anything). Then we picked the bees up with bee-tweezers and put them into a pot with a lid. Then we put the tube with the bee in it into the school's fridge (and made bee pie ☺). The bees fell asleep. Once they fell asleep, we took one bee out at a time and painted little dots on them, like yellow, blue, orange, blue-orange, blue-yellow, etc. We put them into the tube and warmed them up and then let them into the arena. No bees were harmed during this procedure.

*Training phase 2 ('the puzzle' ... duh duh duuuuhhh):* We setup a puzzle for the bees. The puzzle was the following. Imagine having a 16-circle panel with the large square of 12 circles on the outside in yellow with the small square of four circles in the middle blue. This was true for two panels, but the on the other two panels were opposite. So in these other two panels instead of yellow on the outside, larger square and blue on the inside, smaller square, we had blue on the outside and yellow on the inside. The sugar reward (which 1:1 with water) was in the middle 4 flowers in each panel of 16 flowers. Every 10 to 40 minutes we swapped locations of the panels in the different quadrants so that the bees couldn't learn the location of the rewarding flowers. We also cleaned the Plexiglas stems so that the bees couldn't use scent to tell the other bees that that flower had the reward. Instead they had to learn … if the there was blue on the outside ring of each panel of 16 circles, then go to inside 4 yellow circles. If, however, there was yellow on the outside ring, then go to the inside 4 blue circles. During the first two days of training, we had sugar water only in the four middle flowers in each panel and nothing in the outside ring – so that they got the hang of it. During the second two days we added saltwater to the flowers in the outside rings. We did this so that they would learn not to go just to the colours, but had to learn the pattern. Otherwise they might fail the test, and it would be a disaster. After training, we tested the bees to see if they solved the puzzle.

*Testing the bees:* We tested the bees using the same pattern of colours, but without sugar water or salt water to see which flowers they would go to. We also moved the locations of the panels around so it was different from when they were just trained. We let the labelled foragers out into the arena one a time so they wouldn't copy each other (like humans might do). We tracked their flower choices using a sheet of paper with the 64 circles into the 4 quadrants. Whenever the bees landed on a flower and stuck their tongue into the Plexiglas rod, we would mark the same circle on the sheet. We marked each circle with a '1' or a '2' or a '3' etc., so that we could track where they went to see out their behaviour might have change with time. After a while the bees might have got annoyed because they weren't getting a reward and might start making mistakes or searching randomly. So we let each forager make only around 30 choices before we stopped the test. We gave them 3 tests (see Results).

## RESULTS

After training the bees in the arena, we tested them three times to see if they learned anything during training.

*Test 1 (The Control)*

[Figure 1 about here]

In the first test the bees had the same pattern that we trained them on. After training, we moved the colours of panels around clockwise one time so that the colours of the quadrants would be different for the bees. We did this so that the bees could not just go to the same place where they went last time to get a reward. See Figure 1A for a hand drawing of the test. If the bees solved the puzzle, they should land on the flowers in middle of each quadrant and stick their tongue (proboscis) in the flower, since during training this is how they would have got a reward (but during the test, they don't get a reward).

Figure 1B shows where four of the bees went during the test (unfortunately, one of the bees called 'yellow' didn't come out of the hive during this test). Each dot in Figure 1B is an attempted forage. The picture in Figure 1B shows that the bees went to the middle flowers 126 times, and to the outside flowers in each quadrant 13 times (see ‘total’ in Figure 1C). So out of 139 attempted forages, 90.6% were correct flowers (correct means flowers that would have had sugar water during training).

Figure 1C shows how many times each, individual bee went to correct blue and yellow and incorrect blue and yellow flowers. We did this so that it would be clearer where each bee went during the test. ‘Orange’ bee selected 7 correct yellows and only 1 incorrect yellow. She also went to 29 correct blue and only 1 incorrect blue. This bee prefers blue in the middle, but also prefers yellow in the middle. This bee did extremely well, because it went to both colours of correct location of flowers. ‘Blue/Yellow’ bee went to neither outside yellow flowers or middle yellow flowers. Instead it went to 25 correct blue flowers (inside square) and only 4 incorrect blue flowers (outside square). So she preferred blue to yellow. The ‘Blue/Orange’ bee went to 31 correct yellow flowers and 4 incorrect yellow flowers, and never went to blue flowers. The ‘Blue’ bee went to 33 correct yellow flowers and only 3 incorrect yellow flowers, but selected the correct blue flowers only once. These numbers are shown in Figure 1C. We conclude that one bee went to a mixture of colours in correct locations, while the rest preferred one colour more-than another. But while they preferred only one colour, they only went to the middle of the panel that had that colour (since this is the flower that would have had the reward). This test shows that together the bees solved the puzzle very well as their choices collectively were divided between all blue and yellow *rewarding* flowers. We then presented the bees with two more tests to see how they solved the puzzle they were trained to.

*Test 2 (The First Experiment)*

Test 2 is very similar to the Test 1, except that the middle flowers in each quadrant were green. We did this to see if the bees learned to go to the colours or the location of the rewarding flowers during training. If the bees learned to go to the location of the rewarding flowers, then they should land on the green flowers in Test 2. See Figure 2A for a hand drawing of this test.

[Figure 2 about here]

Figure 2B shows a table of the choices where the bees went during this test. In total, the bees went to the green middle flowers only 34 times, but to the outside blue and yellow flowers 76 times (see ‘total’ in Figure 2B). So out of 110 attempted forages, 30.9% were to the middle flowers. If the bees were guessing, they should have selected the green flowers 25% of the time, which is very close to 30%. So we conclude that the bees did not solve Test 1 by only going to the middle flowers of each quadrant (‘dah dahhh dahhhhhh’). However, two of the bees (labelled ‘Blue/Orange’ and ‘Blue’) actually went most often to the green, middle flowers. So they seemed to have learned a different rule to the other three bees.

*Test 3 (The Second Experiment)*

In the third test, instead of having large squares of yellow and blue around the outside of each panel, and a smaller square of yellow and blue on the inside of each panel, we took the four inside flowers and put them in the corners of each panel. See Figure 3A for a hand drawing of what this test looked like. We did this because we wanted to see if the bees solved Test 1 because they learned during training to go to the colours of each panel that were the fewest in number. We could also see if they still preferred to go only to the middle flowers. If the bees learned to go flowers that were fewest in each panel, then should go the flowers that are in the corners.

[Figure 3 about here]

The table in Figure 3B shows where all five of the bees went during the test. You can see that the bees as a group went to the corner flowers 59 times, and to the ‘not-corners’ 86 times (see ‘TOTAL’ in Figure 3B). So out of 145 attempted forages, 40.1% were to the corners. This is very different from what they did in Test 1. When the same flowers were not in the corners but in the middle in Test 1, they selected them 90.1% of the time, which is 2.2 times more often. We think instead that the bees in Test 3 selected the flowers randomly. We conclude that the bees did not learn to go to the flowers that had the fewest colours in each panel. Also, the ‘Blue’ and ‘Blue / Orange’ bees this time did not prefer the middle flowers in each panel. Which means in Test 2 they must have used the larger square of blue and yellow flowers to decided to forage from the *middle* green flowers.

DISCUSSION

This experiment is important, because no one in history (including adults) has done this experiment before. It tells us that bees can learn to solve puzzles (and if we're lucky we will be able to get them to do Seduko in a couples years time). In this experiment we trained bees to solve a particular puzzle. The puzzle was go to blue if surrounded by yellow, but yellow if surrounded by blue.

Test 1 showed that the bees learned to solve this puzzle. We know this because the test results showed that they mostly went to the flowers that they were suppose to go, because they were the ones that were the ones that had had a sugar reward before. But we also noticed that the bees solved the puzzle in different ways, and some were more clever than others. Two bees preferred yellow and two others preferred the blue flowers. The 'Blue' bee was best at understanding the pattern in the first test, because it had the most correct answers compared to incorrect answers. It also went to both correct yellow and blue flowers, but preferred the blue flowers.

What's important about this puzzle is that there is more than one strategy the bees could use to solve it. One strategy would be do use two rules: (i) go to the middle four flowers in each panel and (ii) ignore the colour. Another strategy would be to go to yellow if surround by blue or blue if surrounded by yellow. They could also learn to *avoid* the surrounding flowers, and as a result only go to the middle flowers. Or they could go to the fewest number of coloured flowers in each panel. Of course they could have also just chosen randomly – and they might get them right or they might get them wrong. Or they could have just gone to a colour, but then they wouldn't solve the whole puzzle, only half of it.

Test 2 tests whether the bees learned to go to the middle of each panel and ignore the colour. If the bees learned to go to middle and ignore the colour they should go to the green flowers. If they learned to go to the middle blue and yellow flowers then they should go either to the surrounding blue and yellow flowers or no flowers at all. The results tell us that three of the bees preferred to go to the colours that they learned before and avoid the middle green flowers. Two of the bees, however, mainly went to the middle flowers, including the 'Blue' bee that went to both correct yellow and correct blue flowers during the first (control) test. So they learned to solve the puzzle using different rules. Test 3 also showed that one of the rules wasn't just to go to any middle flower, since they rarely went to the middle flowers, or to go to the flowers that had the fewest colours in each panel, since they did not prefer the corner flowers. Instead they seemed to select the flowers at random, but funnily continued to go to their 'favourite' colour.

We conclude that bees can solve puzzles by learning complex rules, but sometimes they make mistakes. But also that they can work together to solve a puzzle. Which means that bees have personality and have their only 'likings'. We also learned that the bees could use the 'shape' of the different patterns of individual flowers to decide which flowers to go to. So they are quite clever, because they can memorise a pattern. This might help them get more pollen from flowers by learning which flowers might be best for them without wasting energy. In real life this might mean that they collect information and remember that information when going into different fields. So if some plants died out, they could learn to find nectar in another type of flower and so survive during evolution.

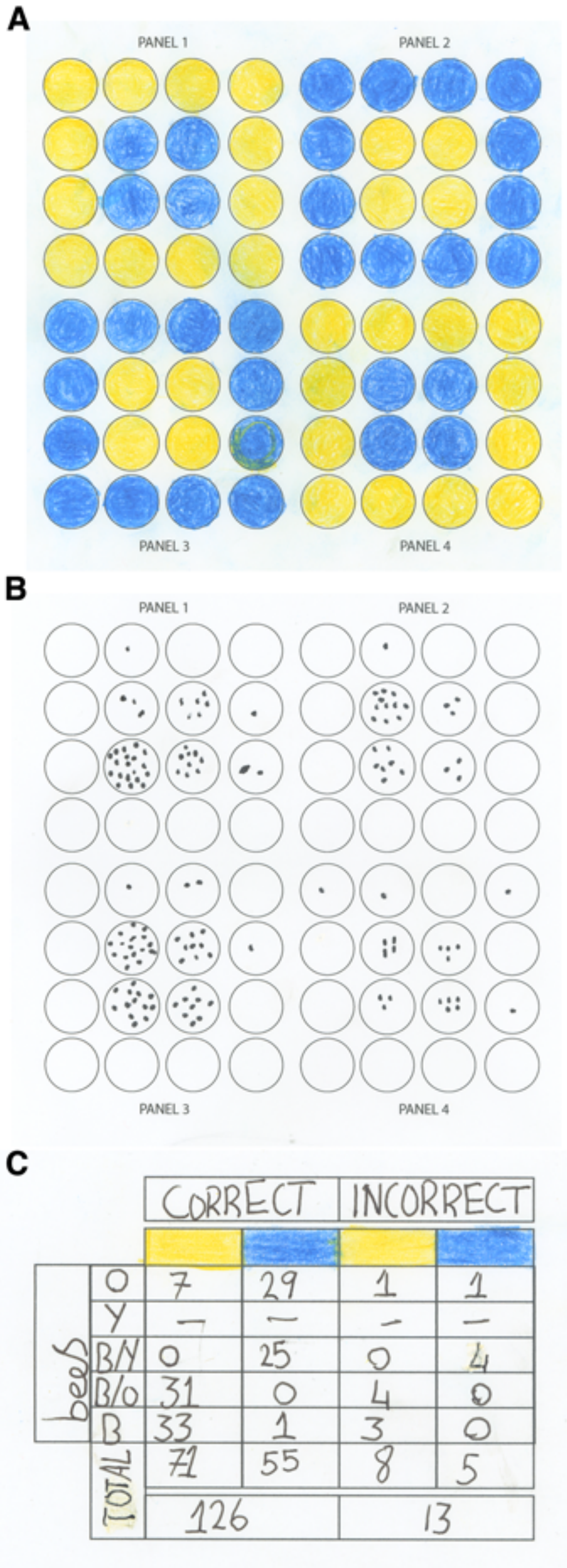
Before these experiments we didn't really think a lot about bees and how they are as smart as us. We also didn't think about the fact that without bees we wouldn't survive since bees keep the flowers going. So it's important to understand bees. We discovered how fun it was to train bees. This is also cool because you don't get to train bees everyday. We like bees. Science is cool and fun because you get to do stuff that no one has ever done before. **(Bees think!)**

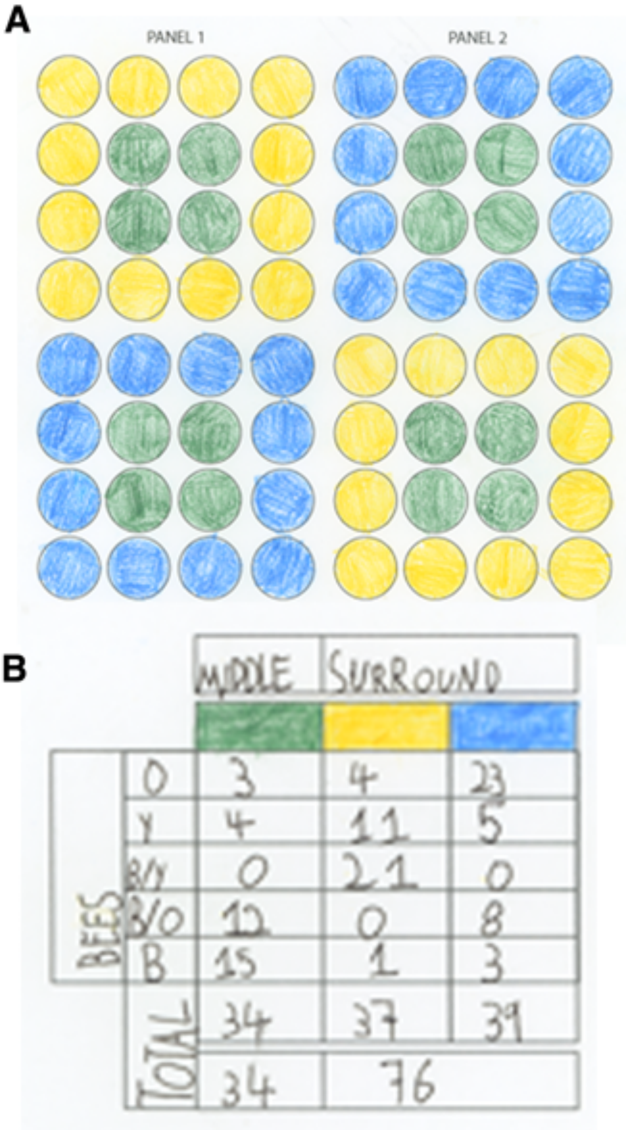
FIGURE LEGEND

**Figure 1:** Conditions and responses to 'Test 1' (The Control). (A) The pattern of colours that the bees were trained to and tested to in their first test (see text for explanation). (B) The selections made by all the bees tested (dots show where each bee landed and tried to get sugar water). (C) A table showing the preferences of each bee during testing (see text for explanation).

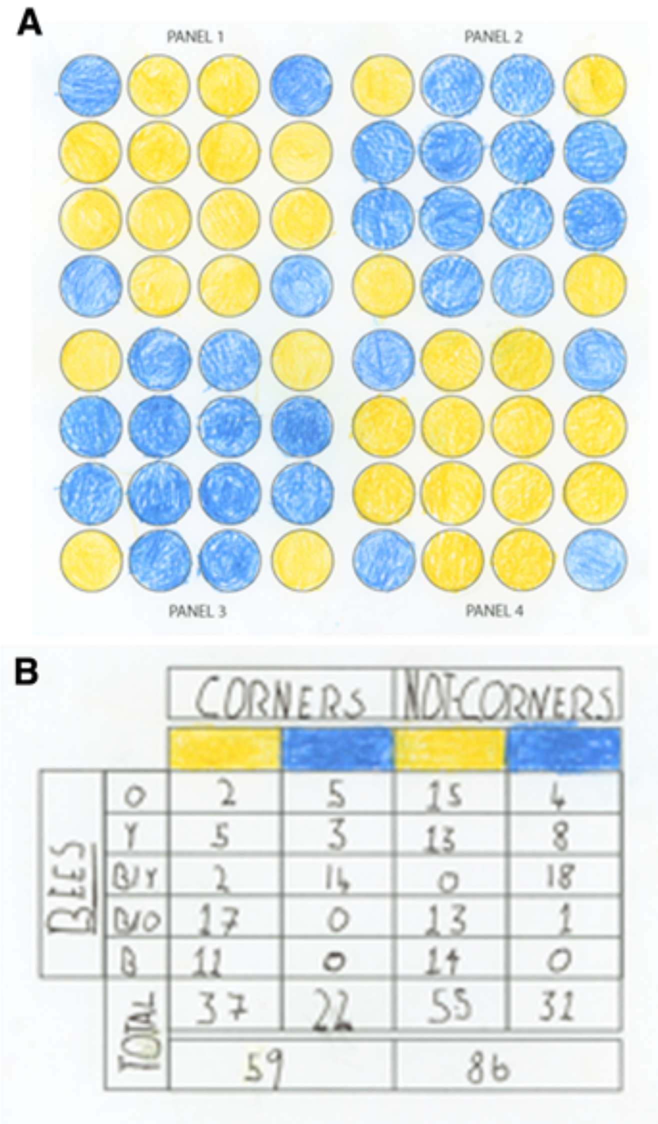
**Figure 2:** Conditions and responses to 'Test 2'. (A) The pattern of colours that the bees were tested to in their second test (see text for explanation). (B) A table showing the preferences of each bee during Test 2 (see text for explanation).

**Figure 3:** Conditions and responses to 'Test 3'. (A) The pattern of colours that the bees were tested to in their third test (see text for explanation). (B) A table showing the preferences of each bee during Test 3 (see text for explanation).


A
PANEL 1
PANEL 2
PANEL 3
PANEL 4
B
PANEL 1
PANEL 2
PANEL 3
PANEL 4
C
CORRECT
INCORRECT
bees
O 7 29 1 1
Y — — — —
B/Y 0 25 0 4
B/O 31 0 4 0
B 33 1 3 0
TOTAL 71 55 8 5
126
13




| | | MIDDLE | SURROUND | |
|---|---|---|---|---|
| | | (green) | (yellow) | (blue) |
| BEES | O | 3 | 4 | 23 |
| | Y | 4 | 11 | 5 |
| | B/Y | 0 | 21 | 0 |
| | B/O | 12 | 0 | 8 |
| | B | 15 | 1 | 3 |
| TOTAL | | 34 | 37 | 39 |
| | | 34 | 76 | |




| | CORNERS | | NOT-CORNERS | |
|---|---|---|---|---|
| | (yellow) | (blue) | (yellow) | (blue) |
| O | 2 | 5 | 15 | 4 |
| Y | 5 | 3 | 13 | 8 |
| B/Y | 2 | 14 | 0 | 18 |
| B/O | 17 | 0 | 13 | 1 |
| B | 11 | 0 | 14 | 0 |
| TOTAL | 37 | 22 | 55 | 31 |
| TOTAL | 59 | | 86 | |