Appendix 3

An engine model of relational psychophysics

Stuart Anstis and Viktor Sarris

A simple *engine model* of the chicken's relational psychophysics is outlined below. It is based on the assumption of the organism's minimum cognitive capacities. For a more lengthy version see Anstis and Sarris (2006). As to the general procedure the reader is referred to chapter 3 (pp. 43–45; see also Appendix 2).

Training and testing

First of all, the chicken must be trained to discriminate a large cube from a small one. The bird views a wooden cube and two pecking keys; one large and one small cube are varied across trials. To keep the numbers simple, let us suppose that the side of the cube is either 2 cm or 4 cm. The chicken's task is to peck the left-hand key if the cube is "large" and the right-hand key if the cube is "small", or vice versa. Correct responses are rewarded with a small amount of food. This apparently simple task can take a chicken three weeks or more to learn even if it practises one hour every day (Sarris, e.g. 1994). When it reaches a criterion of 95 per cent correct in two successive sessions it is considered to be trained. The testing phase begins and one can investigate *context effects* during the post-discrimination generalization phase (test phase), in which the chicken is shown a series of test cubes of different sizes. (Typically the chicken is retrained between test runs to maintain its performance at the criterion level.) During testing, the chicken is shown a new series of cubes of sizes 1, **2**, 3, **4**, 5. These five test cubes are presented repeatedly in random order and the experimenter records the percentage of trials on which each cube size evokes a peck on, say, the right-hand key (small cube).

Three possible context effects: asymmetrical shifts, range effects and frequency effects

Asymmetrical shifts

The test series of 1, **2**, 3, **4**, 5 can be displaced upwards by adding a constant number of cm to each size, such as 3 (new testing range = **4**, 5, 6, 7, 8) or shifted downwards by 0.5 (new testing range = 0.5, 1.5, 2.5, 3.5, 4.5).

Compressed and expanded ranges

A compressed range can be used, still with a mean size of 3, but with a step size of 0.5 instead of 1 cm, thus: **2**, 2.5, 3, 3.5, **4**. An expanded range might have a step size of, say, 1.25; thus: 0.5, 1.75, 3, 4.25, 5.5.

Frequency distributions

For a rectangular distribution, the sizes 1, **2**, 3, **4**, 5 cm are presented equally often. For a triangular distribution favouring large sizes, the range of sizes remains at 1, **2**, 3, **4**, 5 but the frequency distribution is altered, such that the smallest size of 1 cm is presented only once, the 2 cm cube is presented twice, the 3 cm cube 3 times, the 4 cm cube 4 times and the 5 cm cube 5 times. In other words, the following set of sizes is presented in random order: 1, **2**, **2**, 3, 3, 3, **4**, **4**, **4**, **4**, 5, 5, 5, 5, 5 cm. For a triangular distribution favouring small sizes, the range of sizes remains at 1, **2**, 3, **4**, 5 but now the smallest size of 1 cm is presented 5 times, the 2 cm cube is presented 4 times, the 3 cm cube 3 times, the 4 cm cube twice and the 5 cm cube only once. In other words, the following set of sizes is presented in random order: 1, 1, 1, 1, 1, **2**, **2**, **2**, **2**, 3, 3, 3, **4**, **4**, 5 *cm*.

The engine model

Note that the model ("engine model") is presented in the form of an "imaginary chicken", that knows nothing about running averages, ranges, frequencies, nor about excitatory or inhibitory processes. Instead, it uses a very simple strategy that allows it to generate the experimental results, while knowing nothing about the statistics of the stimuli. The aim of the engine model as described below is to *mimic* as much of the behaviour of a real chicken as possible, in order to define as parsimoniously as feasible a lower bound on the abilities of real chickens (*Occam's razor*).

The logic of the engine model

Now imagine a hypothetical situation in which at the end of each trial the experimenter puts the old cube on a shelf and leaves it there, in full view of the imaginary chicken, while the next (new) cube is presented. As for human psychophysics models it is suggested that in this comparative task the chicken will not examine the absolute size of the new cube, but will respond only by pecking the large key if the new cube is larger than the still visible old cube, and by pecking the small key if the new cube is smaller than the old cube. In other words, the chicken is a *difference engine*, responding only to the successive difference in the stimuli, namely the difference in size between successive cubes. Of course there is no actual "shelf" in the experiment on which to store the old cube. The proposal here is that the shelf is in the chicken's *memory* and that in every case the chicken is responding simply to the difference in size between the present stimulus and the remembered previous stimulus. It may be claimed that this simple strategy will generate most or all of the context effects with which the respective literature – at least, with lower animals – is filled. Imagine a series of random permutations of 1, 2, 3, 4, 5 cm; part of such a randomized permutation series might run as shown below:

Number:	4	2	1	5	3	3	2	5	1	4
Difference:		–	–	+	–	=	–	+	–	+

Below each number is a sign (+, –, or =), that shows whether that number is larger (+) or smaller (–) than the number to its left. Thus, under the second digit (2) is a minus sign because 2 is smaller than 4. The third digit (1) also has a minus sign under it because 1 is smaller than 2. The 5 has a plus sign because 5 is greater than 1, and so on. In this model, the row of *plus* and *minus* signs predicts the chicken's responses: Note again that the model chicken responds only to the *sign* (positive or negative) of the difference between successive cubes, and is blind to the absolute magnitude of these differences. It is also blind to the absolute values of the numbers themselves, responding for instance with a *minus* (–) to the first 3 that it sees (because 3 is less than the 5 that it follows) but with a *plus* (+) to the second 3 (because 3 is larger than the 2 that it follows).

One could do a *Monte Carlo* simulation of such an experiment by generating a long string of such digits between 1 and 5, noting the difference (–, +, =) which the model predicts for the chicken's response, and tabulating the results. But one may save the trouble by tabulating simply all possible digits 1 through 5 and their *immediate* predecessors in time, as shown in Table A3.1.

Predicted context effects

We now look at the context effects.

Asymmetrical shift

Suppose that a novel set of test cubes is presented, of sides 4, 5, 6, 7 and 8 cm. The predicted results are shown in Table A3.2.

Table A3.1 Range 1, 2, 3, 4, 5

Size of previous stimulus (cm) →

Size of present stimulus V	*1*	*2*	*3*	*4*	*5*	*Number of larger (+) responses*	*% of + responses (normalized)*
1	=	–	–	–	–	0 / 4	0
2	+	=	–	–	–	1 / 4	25
3	+	+	=	–	–	2 / 4	50
4	+	+	+	=	–	3 / 4	75
5	+	+	+	+	=	4 / 4	100
Total + responses						10 / 20	

Table A3.2 Asymmetrical shift 4, 5, 6, 7, 8

Size of previous stimulus (cm) →

Size of present stimulus V	*4*	*5*	*6*	*7*	*8*	*Number of larger (+) responses*	*% of + responses (normalized)*
4	=	–	–	–	–	0 / 4	0
5	+	=	–	–	–	1 / 4	25
6	+	+	=	–	–	2 / 4	50
7	+	+	+	=	–	3 / 4	75
8	+	+	+	+	=	4 / 4	100
Total + responses						10 / 20	

The hypothetical chicken will *transfer* ("transpose") exactly the responses it made when the range was 1, **2**, 3, **4**, 5 to the new range of 4, 5, 6, 7, 8. In fact, Table A3.2 is identical to Table A3.1 except that the number 3 has been added to every stimulus size. Thus the model predicts a perfect transposition of the chicken's responses, such that a graphic plot of the responses will simply be slid horizontally to the right.

Compressed range

Suppose that the previous test range of 1, 2, 3, 4, 5 is still centred on a mean value of 3 but is now compressed, with the step size reduced from 1 cm to 0.5 cm, resulting in a compressed range of 2, 2.5, 3, 3.5, 4. The results for the model are shown in Table A3.3.

The responses are now compressed to match exactly the new compressed set of test stimuli. In fact, Table A3.3 is exactly the same as Table A3.1 except

Table A3.3 Compressed range 2, 2.5, 3, 3.5, 4

Size of previous stimulus (cm) →

Size of present stimulus V	*2*	*2.5*	*3*	*3.5*	*4*	*Number of larger (+) responses*	*% of + responses (normalized)*
2	=	–	–	–	–	0 / 4	0
2.5	+	=	–	–	–	1 / 4	25
3	+	+	=	–	–	2 / 4	50
3.5	+	+	+	=	–	3 / 4	75
4	+	+	+	+	=	4 / 4	100
Total + responses						10 / 20	

that the stimulus values have been altered from 1, 2, 3, 4, 5 to 2, 2.5, 3, 3.5, 4. When plotted as a function of absolute stimulus size, the chicken's responses are *compressed*. There is nothing magical about this, because our bird has no interest at all in absolute size but is responding only to the *differences* in size – and not even to differences measured in cm but only to rank order. Furthermore, our imaginary chicken never even arranges a set of five stimuli such as 1, 2, 3, 4, 5 or 2, 2.5, 3, 3.5, 4 into rank order, but makes only pairwise comparisons.

Frequency distributions

Table A3.3 tabulates all possible results for a *rectangular* distribution of cube sizes 1, 2, 3, 4 and 5 cm, in which all sizes were equally probable. Now consider frequency distributions that also use stimulus sizes of 1, 2, 3, 4, 5 in favour of some sizes over others by presenting them more or less frequently. Table A3.4(a) and Table A3.4(b) show two *triangular* distributions, in which the different cube sizes are unequally represented. The distribution in Table A3.4(b) favours large cubes, so it comprises one cube of size 1 cm, two cubes of size 2 cm, three cubes of size 3 cm, four cubes of size 4 cm and five cubes of size 5 cm; on the other hand, the distribution in Table A3.4(a) favours small cubes, so it comprises five cubes of size 1 cm, four cubes of size 2 cm, three cubes of size 3 cm, two cubes of size 4 cm and one cube of size 5 cm.

Tables A3.5 and A3.6 show the hypothetical responses that the imaginary chicken makes to these distributions. The columns show the size of the cube that immediately precedes each judgement, and the rows show the size of each cube presently being judged. A plus sign (or a minus sign) in a cell indicates that the present cube is judged as larger (or smaller) than its predecessor. Assume again that the imaginary chicken is a perfect judge of *plus* and *minus*. An equals sign in a cell indicates that the same sized cube is shown twice in succession. These equals cells are omitted from all calculations (in the

Table A3.4 Two triangular distributions of cube sizes:
(a) distribution favours small cubes (see Table A3.5);
(b) distribution favours large cubes (see Table A3.6).

a	1	2	3	4	5	**b**	1	2	3	4	5
	1	2	3	4				2	3	4	5
	1	2	3						3	4	5
	1	2								4	5
	1										5

model they would provoke a "larger" or "smaller" response on a 50/50 random basis).

Tables A3.5 and A3.6 are symmetrical, with the major equal cells running along the negative diagonal and with equal numbers of plus and minus cells lying respectively below and above this diagonal. There are a total of 15 × 15 = 225 cells in each table, but $(1^2 + 2^2 + 3^2 + 4^2 + 5^2) = 55$ cells are the respective "equal" cells. Since, by symmetry, there are equal numbers of plus cells and minus cells (85 of each out of a total of 170 white cells), this model predicts a perfectly performing chicken will respond with "greater than" on 50 per cent of the trials for both distributions. However, this 50 per cent will be differently arranged in the two distributions. For instance, when there are more large cubes, as in Table A3.5, each 2 cm cube will elicit a "greater than" response only once, because there is only one cube smaller than 2 cm (namely, the single 1 cm cube). Since there are only two 2 cm cubes in the distribution, the 2 cm cubes will contribute a total of only two out of the total 85 "larger" responses. On the other hand, when there are more small cubes, as in Table A3.6, each 2 cm cube will elicit five "greater than" responses, because there are five cubes smaller than 2 cm (namely, the five 1cm cubes). Since there are four 2 cm cubes in the distribution, the 2 cm cubes will contribute a total of 20 out of the total 85 "larger" responses. Thus, the 2 cm cubes contributed a total of ten times as many + responses in Table A3.6 than in Table A3.5.

Predictions: effects of relative frequency of cube sizes

Figure A3.1 plots the hypothetical pecks made by an imaginary chicken to a cube drawn from a randomly ordered triangular distribution favouring cubes of small sizes (*upper curve*, open symbols) and large sizes (*lower curve*, filled symbols). These hypothetical responses are taken from Tables A3.5 and A3.6, second column from the right. For instance, in the upper curve (many small cubes) there are five 1 cm cubes, so a 2 cm cube (x = 2) has five changes of following a 1 cm cube and eliciting a + response (y = 5). In the lower curve (many large cubes) there is only one 1 cm cube so a 2 cm cube (x = 2) has only one chance of following it and eliciting a + response (y = 1). Each cube in the

Table A3.5 Distribution favouring large numbers

Prev→ *now V*	*1*	*2*	*2*	*3*	*3*	*3*	*4*	*4*	*4*	*4*	*5*	*5*	*5*	*5*	*5*	# –	# +	*Max*
1	=	–	–	–	–	–	–	–	–	–	–	–	–	–	–	14	0	14
2	+	=	=	–	–	–	–	–	–	–	–	–	–	–	–	12	1	13
2	+	=	=	–	–	–	–	–	–	–	–	–	–	–	–	12	1	13
3	+	+	+	=	=	=	–	–	–	–	–	–	–	–	–	9	3	12
3	+	+	+	=	=	=	–	–	–	–	–	–	–	–	–	9	3	12
3	+	+	+	=	=	=	–	–	–	–	–	–	–	–	–	9	3	12
4	+	+	+	+	+	+	=	=	=	=	–	–	–	–	–	5	6	11
4	+	+	+	+	+	+	=	=	=	=	–	–	–	–	–	5	6	11
4	+	+	+	+	+	+	=	=	=	=	–	–	–	–	–	5	6	11
4	+	+	+	+	+	+	=	=	=	=	–	–	–	–	–	5	6	11
5	+	+	+	+	+	+	+	+	+	+	=	=	=	=	=	0	10	10
5	+	+	+	+	+	+	+	+	+	+	=	=	=	=	=	0	10	10
5	+	+	+	+	+	+	+	+	+	+	=	=	=	=	=	0	10	10
5	+	+	+	+	+	+	+	+	+	+	=	=	=	=	=	0	10	10
5	+	+	+	+	+	+	+	+	+	+	=	=	=	=	=	0	10	10
Total																85	85	170

Table A3.6 Distribution favouring small numbers

Prev→	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*4*	*4*	*5*	# –	# +	*Max*
now V																		
1	=	=	=	=	=	–	–	–	–	–	–	–	–	–	–	10	0	10
1	=	=	=	=	=	–	–	–	–	–	–	–	–	–	–	10	0	10
1	=	=	=	=	=	–	–	–	–	–	–	–	–	–	–	10	0	10
1	=	=	=	=	=	–	–	–	–	–	–	–	–	–	–	10	0	10
1	=	=	=	=	=	–	–	–	–	–	–	–	–	–	–	10	0	10
2	+	+	+	+	+	=	=	=	=	–	–	–	–	–	–	6	5	11
2	+	+	+	+	+	=	=	=	=	–	–	–	–	–	–	6	5	11
2	+	+	+	+	+	=	=	=	=	–	–	–	–	–	–	6	5	11
2	+	+	+	+	+	=	=	=	=	–	–	–	–	–	–	6	5	11
3	+	+	+	+	+	+	+	+	+	=	=	=	–	–	–	3	9	12
3	+	+	+	+	+	+	+	+	+	=	=	=	–	–	–	3	9	12
3	+	+	+	+	+	+	+	+	+	=	=	=	–	–	–	3	9	12
4	+	+	+	+	+	+	+	+	+	+	+	+	=	=	–	1	12	13
4	+	+	+	+	+	+	+	+	+	+	+	+	=	=	–	1	12	13
5	+	+	+	+	+	+	+	+	+	+	+	+	+	+	=	0	14	14
Total																85	85	170

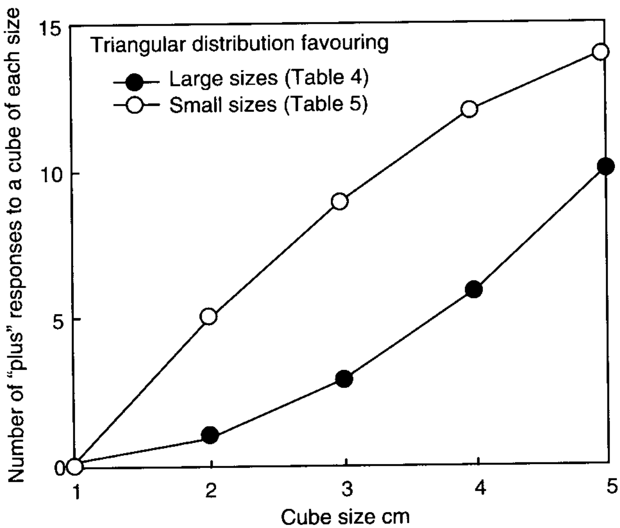

Figure A3.1 Hypothetical pecks made by an imaginary chicken to different sized cubes under two test-series conditions (C1, C2): *upper curve*: test series containing many small cubes; *lower curve*; test series containing many large cubes.

lower curve elicits fewer + responses than in the upper curve, but to compensate for this there are more large cubes in the distribution so that the total + responses in each case add up to 85 (= 50 per cent of all trials). Thus, it is predicted that a chicken's responses to cubes of each size will be strongly influenced by the relative frequency of these sizes in the stimulus distribution. It should be added that this very parsimonious engine model of relational psychophysics allows further predictions, for instance, those of order effects (ascending versus descending event frequencies; see Anstis & Sarris, 2006).

Note

For a general account of the *neuro-informatics* of a behaving organism see, for instance, Bateson and Horn, 1994; Bolhuis, 1999; Braitenberg (1984); Churchland and Sejnowski, 1992/1999; Enquist and Ghirlanda (2005); Erlhagen (2003); Erlhagen and Jahnke (2004); see also Erlhagen and Schöner (2002); Ghirlanda (2002, 2005); Ghirlanda and Enquist (2003); O'Reilly and Johnson, 1994; Solan and Ruppin, 2001; Tarr and Bülthoff (1998).