Title

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A Facet Theory Analysis of the Structure of Cognitive Performance in
New Zealand Robins (*Petroica longipes*)

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In this report, we analyzed the cognitive performance of New Zealand robins (*Petroica longipes*) using facet theory, smallestspace analysis (SSA), and partial order scalogram analysis (POSA). The data set we analyzed was originally subjected to principle component analysis in order to develop a test battery for avian cognitive performance. We extended these analyses by proposing a two facet, rather than a single component, solution using SSA, and we characterized individual birds by their scores on all tasks using POSA. We note problems with the small sample size and call for our exploratory analyses to be replicated using a larger sample of birds and for the development of further test items using the facet theory's tool, the mapping sentence. We suggest that facet theory and the mapping sentences are research approaches suitable for conceiving, designing, analyzing, and developing theory that may be used within avian cognitive research. We conclude that in our methodological comparison, facet-theory-designed research offers a useful alternative approach to principal component analysis when investigating avian cognition.

Keywords: facet theory, mapping sentence, avian cognition, animal behavior

Data reduction approaches such as principle component analysis (PCA) (Du Toit, Steyn, & Stumpf, 1986) have been used in research on the multi-componential area of human cognition, enabling the development of standardized tests and allowing greater understanding of intelligence (Martins, Alves, & Almeida, 2016). PCA has been widely employed to reduce the complexity of data arising from the administration of a battery of human cognitive performance test items and to produce valid and reliable tests of human cognition. As part of a research program investigating the cognitive performance of New Zealand robins (*Petroica longipes*), Shaw, Boogert, Clayton, and Burns (2015) used PCA to develop a six-task test-battery to assess avian cognitive performance. We reanalyzed their dataset using non-parametric multi-dimensional statistics within a theoretical framework of facet theory, which is a method from the social sciences for conceiving, designing, and analyzing research on complex behavior

by investigating the totality of the behavior and its pertinent subcomponents. Louis Guttman originated facet theory (e.g., Guttman, 1954), which has been used to investigate many areas of human behavior and experience (Canter, 1985), including human intelligence and cognitive ability (e.g., Cohen, Fiorello, & Farley, 2006). When using the facet approach, the researcher specifies subcomponents of a research domain (termed facets) and subdivisions of facets (elements), gathers data, and interrogates this using multidimensional statistics. A hypothesized definition of a research domain, composed of facets and elements, is explicitly stated by linking facets/elements together as prose in the format of a mapping sentence. The sentence is used to design research instruments that embody all pertinent variables.

Below is a mapping sentence for category usage in animals:

Animal (x) is: {able; may be trained; unable}**ability** to use: {new; existing}**status**: {perceptual; functional; abstract}**type** types of category, on the basis of: {similarity; difference}**referent** where this is indicated within a: {laboratory; natural habitat}**situation** through the: {speed; complexity; flexibility}**indicator** of category usage, that reflect: {high to low}**range** levels of cognitive complexity (Greggor & Hackett, 2018).

Mapping sentences are read as ordinary English prose. Words in curly brackets are facet elements and one element is chosen from each facet when designing research instruments. Words in superscript and bold are the facet names. The *(x)* designates a specific research sample. In the above example, the first facet is of *ability*, and one of the elements (*able*, *may be trained*, *or unable*) is selected to be included in the sentence. The connective words *to use* are read, an element is selected from the *status* facet (*new* or *existing*), and then, an element from the *type* facet (*perceptual*, *functional*, or *abstract*) is read. The connective words *types of category, on the basis of* are read, and the procedure is repeated up until the final (*range*) facet, which specifies the measurement that will be made.

Subsequently, the mapping sentence becomes a hypothesis for how birds experience the area of interest and provides a systematic methodology for the classification of a complex research domain (Hackett, 2017a, b, & c, 2016, 2014). Facet elements must be as near as possible mutually exclusive subcategories, and the logical interrelationships between facets define a mapping sentence that addresses an overall research question. Data are gathered using instruments designed using the mapping sentence and data are analyzed with statistical techniques (smallestspace analysis [SSA]; partial order scalogram analysis [POSA]) to test the hypothesized structure in the mapping sentence. A mapping sentence enables the investigation of specific behaviors and is a specific contextualization of the facets and elements for the research domain of interest. It is also possible to perform exploratory analysis of non-mapping-sentence-designed research data.

Shaw et al. (2015) analyzed New Zealand robins' performances on a 6-task avian test battery using PCA, which suggested a possible latent structure for cognitive test performance. We used SSA and POSA, which have similar analytical aims as PCA. However, by using weak monotonicity coefficients upon rankings of scores, SSA does not impose linearity or parametrical assumptions upon the data. SSA is a form of graphical analysis that finds correlations between items and represents items as positions in two-dimensional space, where the items are located closer to each other the more they are correlated. When spatially representing the correlation between a number of data points (items), there will be some degree of inaccuracy. A coefficient of alienation (CoA) indicates the accuracy of the results (0 = all items perfectly positioned; 1 = maximum level of inaccuracy). In SSA plots, the procedure draws lines that attempt to exclusively capture items with similar scores for a facet element by using lines that are as straight as possible or circles. The degree to which this form of partitioning is possible is a test of the validity of a facet and its elements.

Having identified facets and elements in SSA, a profile of scores by individual birds on each element can be developed and analyzed using POSA, which considers relationships within and between profiles of scores for individual birds. For example, a bird can be assessed on a series of tasks that it was able to perform (2) or was not able to perform (1) and a profile can be written: 121112212. There are quantitative differences (summation of profile scores) and qualitative differences (scores on an individual item). Thus, 222111211 is quantitatively the same as 121112212 but qualitatively different. POSA plots individual birds in a two-dimensional space with quantitative differences running from bottom left (lowest) to top right (highest). Simultaneously, birds with similar scores on individual items are located adjacently from top left to bottom right. Straight lines are drawn to capture similar scores for each item using six permissible partitioning shapes. The shapes created by the lines reveal the qualitative and quantitative differences, with a CoA determining the accuracy of a POSA.

By using a mapping sentence, we attempted to reveal the structural interplay between pertinent facets of avian intelligence and to offer insight and understanding of birds' cognitive processes. We now present details of the original research and data.

Psychometric Data Set

Shaw et al. (2015) gathered data at a wildlife sanctuary in New Zealand. The birds in the sample were 20 adult New Zealand robins (*Petroica longipes*) (14 males, 4 females, 2 sex unknown); however, 3 birds went missing prior to completing all tasks. The birds were ringed using colored plastic rings. The birds voluntarily participated in taking the test battery, which comprised six tasks presented in a standardized order: (1) motor task; (2) color discrimination; (3) color reversal; (4) spatial memory; (5) inhibitory control; and (6) symbol discrimination. All of the tests involved training and were assessed in terms of the number of trials to criterion performance attainment. Each of the tests had an individualized protocol and scoring procedures (see Shaw et

al., 2015). Shaw et al. (2015) discovered that 4 of the 15 between-task correlations were negative. The motor task possessed the greatest number of negative associations, four, although these were of very small magnitude (-0.178; -0.034; -0.032; -0.008). They investigated the structure of task relationships using PCA discovering two principal components.

All tasks loaded positively on Component 1 using the criteria of eigenvalues being above unity, which accounted for 34% of variance on all tasks. The motor task and symbol discrimination did not load heavily on this component but loaded positively on a second component, which accounted for a further 14% of variance (59% of total variance in the data set). The loading of the six tasks on the two principal components is displayed in Table 1.

Table 1
Principal Component Loadings (adapted from Shaw et al., 2015)

Subtest	PC1	PC2
Spatial memory (4)	**0.727**	0.184
Inhibition (5)	**0.695**	0.333
Color discrimination (2)	**0.660**	0.084
Color reversal (3)	**0.631**	0.274
Motor task (1)	0.231	**0.887**
Symbol discrimination (6)	0.411	**0.673**
Eigenvalue	*2.067*	*1.466*
% Variance explained	*34.46*	*24.44*

Note. Numbers in parentheses are the original test order and the numbers on the SSA and POSA plots. In this table, the order of tasks (subtests) has been arranged by their loading on the two principal components and loadings above 0.6 have been highlighted (copying Shaw et al., 2015). Key: PC = principle component; SSA = Smallestspace Analysis; POSA = Partial Order Scalogram Analysis.

Smallestspace Analysis: Revising Shaw et al. 2015

   Correlation.   We initially calculated correlations between all task pairings (Table 2).

Table 2
Weak Monotonicity Coefficients Between Subtests (n = 16)

	Task #	1	2	3	4	5	6
MotorTask (1)	1	*1.00*					
ColDiscrim (2)	2	0.40	*1.00*				
ColReverse (3)	3	-0.18	0.29	*1.00*			
SymbDiscrim (6)	4	0.70	0.09	0.31	*1.00*		
SpatialMem (4)	5	0.11	0.59	0.61	0.13	*1.00*	
Inhibition (5)	6	-0.23	0.44	0.52	0.25	0.59	*1.00*

Note. Numbers in parentheses are the original test order and the numbers on the SSA and POSA plots. The coefficients in this table are different from those in the analyses in Shaw et al. (2015) due to the use

of a different statistic to calculate the coefficients (linear coefficients in the case of Shaw et al. (2015), monotonic in our case). Key: ColDiscrim = Color Discrimination; ColReverse = Color Reversal; SymbDiscrim = Symbol Discrimination; SpatialMem = Spatial MemoryPC = principle component; SSA = Smallestspace Analysis; POSA = Partial Order Scalogram Analysis.

If the six tasks are all, to some extent, measuring avian intelligence, then all tasks should possess a monotonic relationship. Nearly all of the weak monotonicity coefficients were positive (positive = 13, negative = 2), suggesting that the content area addressed a single construct (avian intelligence). The two low negative coefficients were both associated with the motor task (-0.18 and -0.23: respectively, color reversal and inhibition tasks). This may suggest that the motor task was accessing a slightly different latent variable than the other five tasks. However, the largest positive coefficient in the matrix was between motor task and symbol discrimination suggesting that the motor task is a valid task within the battery. This suggests the psychological content covered by the six tasks in the task battery is relatively homogeneous, with motor task assessing a slightly different ability than the other five tasks.
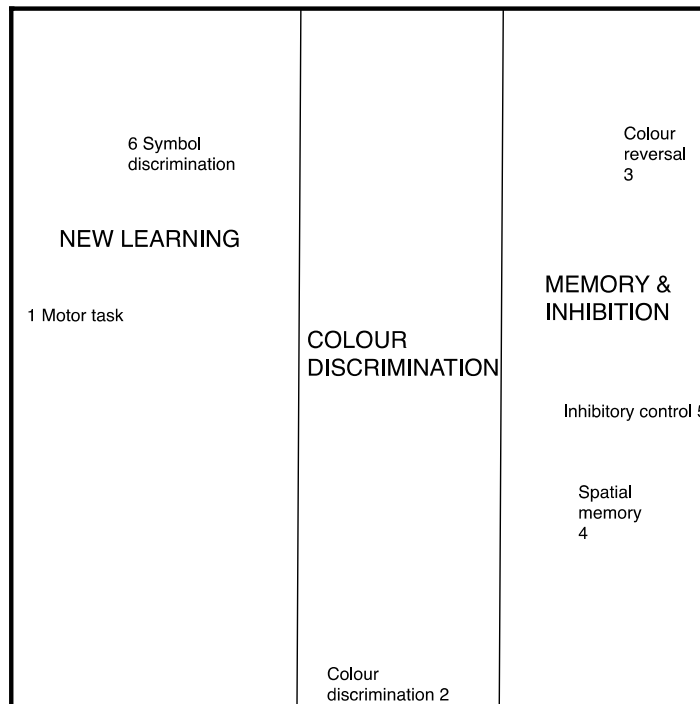

6 Symbol discrimination

NEW LEARNING

1 Motor task

COLOUR DISCRIMINATION

Colour reversal 3

MEMORY & INHIBITION

Inhibitory control 5

Spatial memory 4

Colour discrimination 2

Figure 1. **Space diagram for one-facet smallestspace analysis for task-type facet.**

One-facet solution. As Shaw et al. (2015) discovered one factor, we employed a one-faceted solution, which had a very low CoA (Coefficient of Alienation) (0.09). The single facet was partitioned into three regions or elements in what is known as an axial arrangement (see Figure 1), suggesting that task completion skills were distinct,

with some tasks being more closely associated with some other tasks but less associated with some other tasks. We named this facet *task-type*. We compared our one-facet solution with Shaw et al.'s (2015) PCA in Table 3 and offer an initial mapping sentence for this research domain in Figure 2.

Table 3
Single-Facet Analysis and Principle Component Analysis

Subtests	Facet Element New Skill Learning	Facet Element Color Discrimination	Facet Element Memory and Inhibition	Principle Component 1	Principle Component 2
Motor task (1)	yellow				green
Symbol Discrimination (6)	yellow				
Color discrimination (2)		orange		brown	
Spatial memory (4)		orange		brown	
Color reversal (3)			light blue	brown	
Inhibitory control (5)			light blue	brown	

Note. Numbers in parentheses are the original test order and the numbers on the SSA and POSA plots. The color legend is provided below.

Legend

Task-type Facet	New skill learning	yellow
	Color Discrimination	orange
	Memory and Inhibition	light blue
PCA	First Component	green
	Second Component	brown

	Task type
	(new skill learning)
The response from Robin (x) that required the use of:	(color discrimination)
	(memory and inhibition)
	Range
	(correct)
to complete the task, was assessed to be:	(to)
	(incorrect)

Figure 2. **Initial mapping sentence for avian cognitive performance.**

Two-facet solution. As Shaw et al. (2015) discovered a second component, we conducted two facet SSA. Conducting SSA with a greater number of dimensions allows for the identification of patterns in correlations in the data set that are not revealed when using a single facet. Furthermore, if a higher number of facets are calculated when a greater number of facets are not present in the correlations, the facets produced will be repetitive or they will be impossible to interpret meaningfully. A two facet SSA (Figure 3) yielded an exceptionally low CoA (0.00).
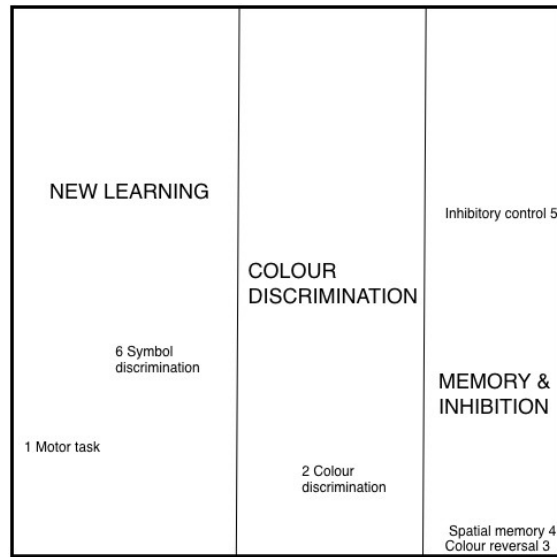
Figure 3. **Space diagram for two-facet SSA: Task-type facet.**

In this analysis, two facets emerged. The first had a similar axial structure as the single-facet solution (Figure 3) along with a second modular structure (focus) facet with the elements of central/general and peripheral/particular (Figure 4). In a modular facet, some items are more strongly correlated with all other items and thus are more centrally located in the item plot. In our analyses, the motor task was positioned at the center of the item plot, indicating performance of this task was at least moderately associated with all other tasks. This centrality is upheld by the fact that the motor task was taught to the robins before and formed the basis of, or was at least related to, their subsequent performance on the other tasks. This second facet focused task performance in terms of the centrality/generality of the behavior necessary to complete the six tasks.
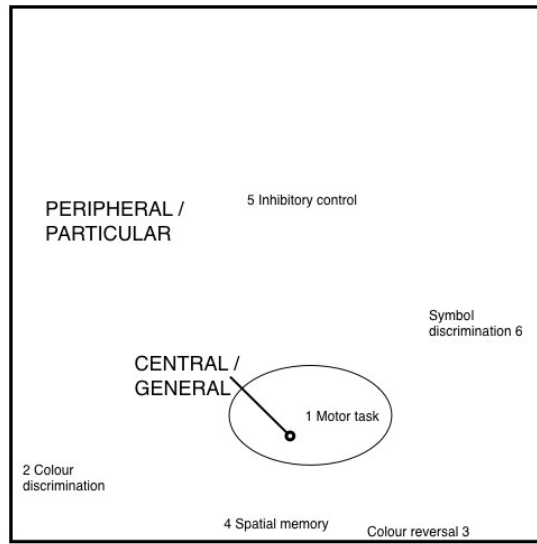
Figure 4. **Space diagram for two-facet SSA: Focus facet.**

As the facets of task-type and focus were in separate plots, their psychological processes did not have a combined effect. Their interaction may be depicted as an orthogonal relationship and drawn as a cylindrical structure (Figure 5), which demonstrates that central and peripheral tasks may be concurrently classified as requiring new skill learning, color discrimination, or memory and inhibition skills. As well as diagrammatically demonstrating the combined effects of the two facets, we modified the mapping sentence to demonstrate the combined relationship of the two facets (see Figure 6).
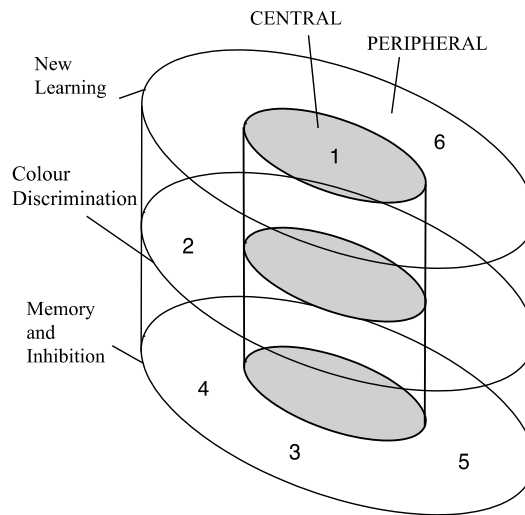

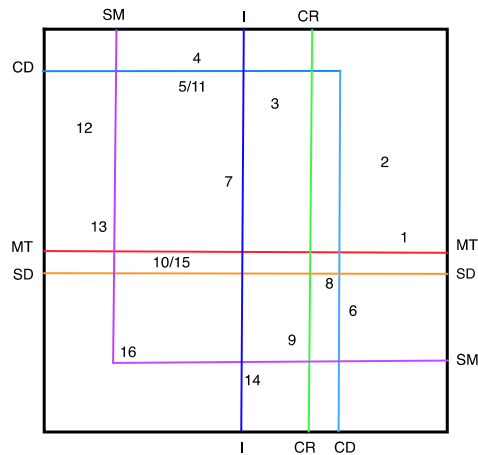
Figure 5. **Two-facet cylindrex.**

Figure 6. **Partitioning for POSA.** Each task is represented by a specific color of line. Tasks with lines that partition space in a similar direction and with a similar shape have similar psychological content in respect to avian cognition (e.g., MT and SD). Partitions that are orthogonal to each other have relatively independent content (e.g., I and MT, SD). Tasks that partition into L or inverted L shapes (e.g., SM and CD) moderate the processes associated with the tasks that partition into vertical and horizontal regions. The L and inverted L tasks moderate in opposite directions to each other.

Partial Order Scalogram Analyses: Revising Shaw et al. 2015

We recoded data into dichotomous variables splitting at the theoretical mid-point. Our POSA (see Figure 6 represents each of the individual birds as numbers in the plots. The birds are positioned from bottom left (low score) to top right (high score) in terms of a bird's summated score on all tasks (e.g., Bird 16 had the lowest summated profile score and are nearest the bottom left, and Birds 1, 2, 3, and 4, who all achieved the highest summated scores, are nearest to the top right). Their scores on individual elements of their score profiles determine the position of birds from bottom right to top left.

The direction and shape of the lines in Figure 6 shows the relationships of tasks to overall performance and relationships between tasks. The tasks of inhibition and color reversal partitioned to form horizontal regions that captured similar scores for each task. As partitioning was in a similar direction, these two tasks had a similar effect structuring robins' responses. Two tasks, motor task and symbol discrimination, partitioned space into vertical regions demonstrating the tasks to exert a similar effect upon robins' performance. As partitioning of inhibition and color reversal (horizontal regions) and motor task and symbol discrimination (vertical regions) are opposite to each other, they played independent roles in task completion.

Figure 6 also shows that the spatial memory task partitioned space into an "L" shaped region whilst the color discrimination task partitioned space into an "inverted L" shaped region. The "L" and "inverted L" partitioning shapes demonstrate these variables moderate the effects of horizontally and vertically partitioned variables.

However, the two different "L" shapes show the tasks to play opposite roles with the directional differences demonstrating that the two tasks play qualitatively distinct roles. A representation of how the facets and elements combine in POSA can be seen in Figure 7.

The response from Robin (x) that required the use of:

Task type
(new skill learning   )
(color discrimination   )
(memory and inhibition)

skills, that are: **Focus**
(peripheral/particular)
(central/general   )

to the completion of the task,

were assessed to be: **Range**
(correct)
(to   )
(incorrect)

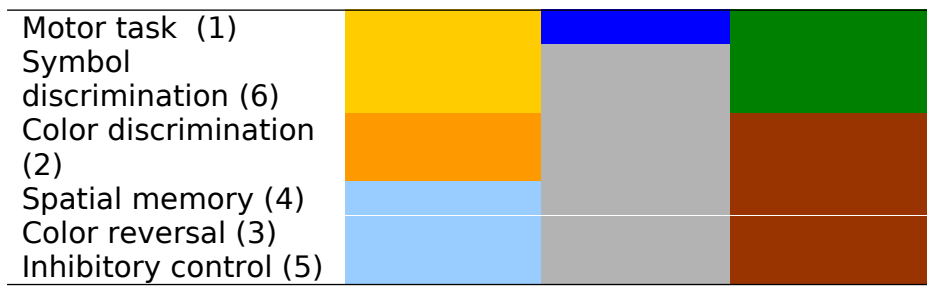*Figure 7.* **Mapping sentence for avian cognitive performance**

Discussion

The value of a reanalysis rests upon the ability of the new analysis to offer findings that add to the knowledge produced in the original analysis. Our two-facet solution was our preferred solution as it demonstrated that the facet elements differentiate between the similarities and differences in test battery tasks. Furthermore, these elements reflect the design and implementation of the avian task battery. The grouping of tasks into three qualitatively distinct regions (*new skill learning/visual shape*, *color discrimination*, *memory and inhibition*) suggests each region constitutes a distinct type of task for the sample of robins. The concurrent allocation of tasks to regions reflecting the central or peripheral nature of the task suggested this form of discrimination was also present.
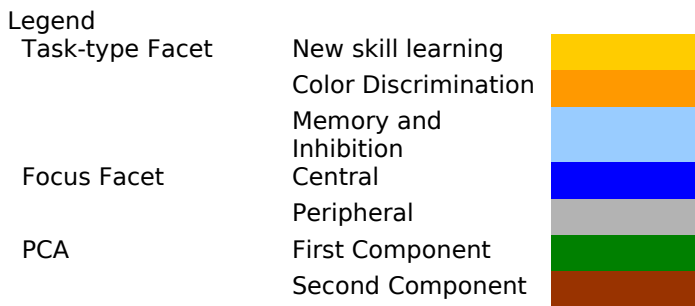
Table 4 illustrates that the facet of task-type supports Shaw et al.'s (2015) second component. However, SSA suggests that Shaw et al.'s (2015) first principle component could be subdivided (into color discrimination and memory and inhibition) to reflect a bi-partite structure for the four tasks in this principle component. We present a comparison of Shaw et al.'s (2015) principal components and our two-facet solution in Table 4.

Table 4
Two-Facet Analysis and Principle Component Analysis

Subtests	Facet of Task-type	Facet of Focus	Principle Component Analysis

Task	Task-type Facet	Focus Facet	PCA
Motor task (1) Symbol discrimination (6)	New skill learning (yellow)	Central (blue)	First Component (green)
		Peripheral (grey)	
Color discrimination (2)	Color Discrimination (orange)	Peripheral (grey)	Second Component (brown)
Spatial memory (4) Color reversal (3) Inhibitory control (5)	Memory and Inhibition (light blue)	Peripheral (grey)	Second Component (brown)

Note. Numbers in parentheses are the original test order and the numbers on the SSA and POSA plots. Note the legend below regarding the color scheme.

Legend

Task-type Facet	New skill learning	(yellow)
	Color Discrimination	(orange)
	Memory and Inhibition	(light blue)
Focus Facet	Central	(blue)
	Peripheral	(grey)
PCA	First Component	(green)
	Second Component	(brown)

The task type facet had the following elements.

New skill learning (visual shape). This element contained motor task and symbol discrimination tasks. POSA and SSA suggested novelty rather than any particular type of skill linked these tasks. Both tasks also related to visual discrimination of shape.

Color discrimination. This element contained a single task (color discrimination) and consequently it is not possible to evaluate the relative valence of color or the discriminative act. However, further color discrimination tasks may be designed to assess the psychological nature of this element.

Memory and inhibition. Containing spatial memory, color reversal and inhibition that required the use of memory and subsequent inhibition of an initial responses. Our analyses also support Shaw and colleagues' (2015, p.108) claim that inhibitory and color reversal were related.

Color, per se, did not appear to constitute an independent task type as the color reversal and color discrimination tasks occupied different facet elements. Similarly, discrimination tasks did not occupy the same element. Further research is needed to address the pertinence of both color and discrimination related tasks to birds.

The second facet we found had modular format. The modular structure formed concentric circles with central tasks being more general than peripheral ones and having higher intercorrelations with other items than peripheral items. Furthermore,

adjacent item pairs that fell within a region that was of a particular distance from the center of the plot possessed correlations that were approximately equal. Correlations decreased as regions become further from the central origin. Modular facets are commonly found in the same plane as another facet, but this was not the case in our analyses (modular format facets were found in analyses of human intelligence; Guttman & Levy, 1991).

POSA concurrently analyzed all individual birds' performance upon all six tasks and graphically portrayed these performances (see Figure6. In Figure 6 the numbers represent individual birds positioned along two axes, the first is from bottom left to top right of the square. Along this dimension, birds are located in terms of a bird's summated score (low to high) on all tasks (Bird 16, with the lowest summated profile score, was nearest the bottom left, and Birds 1, 2, 3, and 4, with approximately the highest summated scores, were nearest the top right.

The direction and shape of the lines in Figure 6 make it possible to understand the relationships of tasks to overall performance and the relationship between tasks. The tasks of inhibition and color reversal both partitioned to form horizontal regions. As their partitioning lines were in a similar direction, these two tasks were intimately related to each other in terms of the effect they have on structuring robins' responses. The motor task and symbols discrimination task partitioned space into vertically separated regions, again showing these tasks to exert a similar effect upon robins' performances. The partitioning of inhibition and color reversal (horizontal regions) and motor task and symbol discrimination (vertical regions) were opposite to each other and played independent roles in task completion.

The spatial memory task partitioned space into an "L" shaped region, whilst the color discrimination task partitioned space into an "inverted L" shaped region. The "L" and "inverted L" partitioning demonstrates that these variables moderate the effects of the horizontally and vertically partitioned variables. The two different "L" shapes show the tasks to have played opposite roles, supporting the positioning of spatial memory and color discrimination in different facet elements. Figure 7 demonstrates how the facets and elements combine in POSA.

Conclusions

The assessment of avian cognition in the location in which it usually occurs (in the wild or natural setting) is in its infancy. We reanalyzed Shaw et al.'s (2015) data set. This data set has several limitations that we have noted in this article. Further research is needed to provide support for the form of analysis that we propose. However, the present data set, even with its limitations, represents a unique assessment of avian cognition and, we believe, illustrates the utility of the facet theory approach as an addition to the techniques available to avian researchers.

We discovered two facets, one reflecting task type and the other the generality or particularity of a task, accounted for variation in Shaw et al.'s (2015) data matrix. Their data set was comprised of 16 birds completing 6 tasks. Analysis of such small data sets are prone to overfitting (i.e., the analysis corresponds too exactly to the data set and cannot reliably predict future observations). The small sample size and the small number of performance tasks make it problematic to produce reliable findings. The facet approach cannot eliminate overfitting but may mitigate the problem by producing a mapping sentence template for future research that may provide support or refutation for an analysis. A much larger data set is required in order to produce robust results and to allow confidence in the findings of Shaw et al. (2015) and the present analyses. A much larger sample, or repeated small samples of birds, needs to be examined using the mapping sentence we have produced. At least 10 observations per variable, and exceptionally 5 observations, are usually considered a minimum for PCA. Moreover, the sample involved birds participating voluntarily, which does not allow for an understanding of the sample's representativeness. Under a facet theory approach, small samples and individual cases may be analyzed and the validity/reliability of results demonstrated through repeatedly using the same mapping sentence and comparing results. The ability of the facet approach to offer insight when employing a small sample size and a limited number of test items makes it particularly appropriate for use within animal cognition studies.

Facet element names were chosen to reflect the tasks that composed each element; however, these were initial suggestions and further research is needed with a greater number of items in order to support or refute these. Our two-facet solution only represents the underlying structure of the cognitive test battery data and not avian cognition per se, and analyses were exploratory and upon a data set that was gathered using procedures not designed using a mapping sentence. Consequently, facet theory driven research is needed in order to support, refute, or modify our claims regarding the data's latent structure. Future research needs to design subtests and tasks based upon the findings of SSA and POSA in order to better assess the veracity of these structures and the latent variables suggested, and tasks need to be designed that reflect the skills and performance associated with all facet elements. Existing tasks could be modified using, for example, less abstract symbols than the geometric designs employed in this research. Human intelligence subtests are composed of many items and not a single test, and it is important that multiple tasks are developed for each of the facet elements in the mapping sentence for avian cognitive performance (Figure 6). We believe the analyses we have presented offer a viable and useful alternative to PCA when analyzing avian cognition.

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