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The Mental Number Line in Domestic Chicks

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Abstract

The estimation of number by humans shows evidence for a mental number line in which magnitude increases from left to right. Rugani, Vallortigara, Priftis, and Regolin (2015) recently reported a similar mental number line in domestic chicks. This is an unexpected result given the role of language and culture in the human mental number line. Animals do not possess language or arithmetic concepts like the mental number line. Because the results reported by Rugani et al. (2015) seem improbable from this perspective, my study sought to determine whether the observations of Rugani et al. (2015) occur reliably. I tested for the occurrence of a mental number line in domestic chicks following as closely as possible the procedure described by Rugani et al. (2015). Domestic chicks were trained and tested for left / right preferences in a food-rewarded choice task. Chicks were trained to find food behind an opaque panel with varying arrangements of 5 red squares. Two identical panels with the same number of red squares on each were presented in each test. The number of squares was either large or small compared to the number of squares the chicks had seen on a sample panel. The prediction was that if the number on the test panels was small compared to the sample, chicks would choose left and if it was large chicks would choose right. The chicks showed no left / right preference. I found no evidence that a mental number line plays a role in domestic chicks' numerical abilities.

The Mental Number Line in Domestic Chicks

The mental number line is the tendency to associate smaller numbers with left space and larger numbers with right space. Humans as young as 5 years old are able to conceptualize a mental number line, as long as they are familiar with the numerical range provided (Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008). The mental number line is thought to be culturally based, and may differ depending on which direction text is read in a particular language. It has been found that members of Western cultures respond faster to small numbers presented in the left visual field and large numbers in the right visual field (Ebersbach et al., 2008).

Innate Ability

The mental number line in human infants has been examined by Hevia and Spelke (2010), who showed that it is present in many cultures and depends on the direction of reading in each language. However, little is known, regarding the developmental origin of this trait. Western infants have been shown to begin using left to right number space mapping only once they enter pre-school. The study conducted by Hevia & Spelke (2010) explored the mental number line in infants at 8 months old, using a habituation/novelty task. The infants were familiarized with increasing or decreasing numbers of visual stimuli (coloured squares and circles). Tests consisted of horizontal lines that had both novel and familiar increasing/decreasing value patterns. Sensitivity to the direction for increasing (or decreasing) number value was seen in the infants when they tended to look longer at novel increases or decreases in numerical value. If the number pattern increased in the habituated task, the infant stared longer at a novel pattern in which the number pattern decreased. These results show the understanding of numerical magnitude at a young age and possibly the presence of a mental number line. Infants learned the number-length relationship in familiarization displays and

generalized this to new numbers and lengths in test displays. Therefore, infants were sensitive to the positive number-length mapping.

The Mental Number Line in Other Cultures

Núñez (2011) describes how the mental number line is culturally and historically shaped. It has been found that some indigenous Australian groups map numbers onto a two-dimensional plane rather than a one-dimensional line. Most mental number line studies show a faster response of the left or right hand to numbers of varying magnitude. However, smaller or larger numbers within a range have been found to be responded to faster with a close versus far key response (Núñez, 2011).

Other findings show that not all humans through history have used the mental number line. Old Babylonians had complex mathematic abilities related to fractions and operations without reference to a mental number line. Numbers were used for measurement but not associated with a number line orientation. It is believed that use of the mental number line emerged in 17th century Europe (Nunez, 2011).

Recent studies of mental number line in indigenous groups of the Amazon and Papua New Guinea have been compared to the results seen in young Western children. The Munduruku people of the Amazon have a small lexicon for numbers comparable to the numbers 1-5. They were found to be unable to map the end numbers within the range on a visual number line and unable to place numbers along the line when instructed verbally (Dehaene, Izard, Spelke, & Pica, 2008). In comparison, Western children were able to designate anchors (ends of a number line) for 0-100 on a visual number line task even though they did not have a fully formed number line. Results show that the mental number line is a component of the modern world and reinforced by cultural practices (Dehaene, Izard, Spelke, & Pica, 2009). Humans have an evolutionarily driven

hard-wired mechanism for understanding numerosity and the perception of magnitude and stimulus intensity. However, the actual mental number line orientation of numerical values is culturally determined and not innate. The strong evidence of a cultural and linguistic influence raises questions about the occurrence of the mental number line in non-linguistic animals.

Spatial Numerical Association of Response Codes

The Spatial-Numerical Association of Response Codes (SNARC) effect is displayed in humans, based on the mental number line concept. A study conducted by Dehaene, Bossini, and Giraux (1993) required French participants to perform a parity judgement task. Participants responded to a number on a screen indicating if it was even or odd with computer keys. Even and odd labels were on left or right response keys. Two conditions allowed participants to experience both a 0-5 interval condition and a 4-9 interval condition. Participants responded faster to larger numbers with their right hand and smaller numbers with their left hand. The effects were perceived for numbers within an interval, not the general magnitude of a number. This was shown when the number 5 had differing response rates depending on the interval condition (0-5 versus 4-9) it occurred in. Individuals demonstrated a significant SNARC effect.

The study was repeated using letters but no SNARC effect was found. Instead of a parity judgement task, participants had to distinguish letters on a screen as either in an ACE category or BDF category. It was hypothesized that the letters further to the end of the alphabet would be responded to faster with participants' right hand and letters closer to the beginning of the alphabet faster with their left hand.

Previous studies have been conducted to compare languages with differing reading direction of text and the effects on the SNARC effect. A study using Russian-Hebrew participants allowed for the SNARC effect to be examined in diverse cultures (Shaki & Fischer,

2008). Russian reads from left to right whereas Hebrew reads from right to left. All participants were fluent in both languages and preformed a parity-judgement task similar to the study described previously. Prior to testing on the parity-judgement task, participants were primed by either reading a Hebrew or Russian paragraph. Results indicated that those who were primed with Russian text displayed a SNARC effect (left to right bias). However, participants who read the Hebrew text displayed a weaker SNARC effect. The Hebrew prime may have not fully reversed the SNARC effect due to the fact that Hebrew represents numbers in a left to right direction.

Subsequent trials of the study were done using auditory stimulation for the Hebrew/Russian primes but no SNARC effect was found in these trials. This study shows the cultural impact on the SNARC effect and that the SNARC effect may be a flexible spatial strategy rather than a fixed habit.

Domestic Chicks

The SNARC effect has been shown in domestic chicks. A study by Rugani, Vallortigara, Priftis, and Regolin (2015), found a significant SNARC effect in 3 day-old domestic chicks. Chicks were trained to find a mealworm behind a white opaque stimulus panel. Once the chick accomplished food retrieval 5 times, training continued. Further training consisted of the chick finding the mealworm behind the white opaque panel 20 times but the stimulus (board) had 5 red square (stimuli) of equal shape and size displayed on the front of it. Each of the 20 trainings had a new arrangement of red squares on the panel. Testing consisted of large number and small number conditions. The small number condition involved two identical stimulus panels of 2 red squares. The large number condition was the same but with 8 red squares on each panel. Results showed that the chicks searched for food behind the right panel in the large number condition

and behind the left panel in the small number condition. The chicks were trained with the 5-stimulus panel so 2 would be in the left space on a mental number line and 8 in the right. Further trials controlled for non-numerical features of the displays on apparatus panels such as shape, colour, size, total surface area, total perimeter, and area so that preference could only be influenced by numerosity.

Rugani et al. (2015) suggest that the SNARC effect may be explained by hemispheric asymmetry of avian brain function. A right hemispheric dominance for numerosity may cause leftward attention and induce birds to estimate quantity from left to right. Numerical representations have been found to be spatially organized in the human brain, especially in the parietal cortex (Droit-Volet, & Coull, 2015). Further research may explain origins of the mental number line in the avian brain.

Preference in eye use was shown in previous studies with birds by measuring the speed at which a chick searches for a familiar object when one eye is patched (Vallortigara, 2000). A faster speed of search indicated preferred eye use. Visually guided motor responses may thus depend on cerebral lateralization.

Further studies also support the idea that domestic chicks may be able to form a mental number line (Vallortigara, 2000). Left and right eye use as well as, left and right hemisphere use may bias responding depending on the task or spatial cue presented. The left eye and right hemisphere may encode spatial cues, whereas the right eye and left hemisphere may encode object specific features.

Lateralization and Numerical Ability in Vertebrates

Cerebral lateralization has been shown in several fish and amphibian species. Poeciliid fish showed a leftward preference of motor responses on a detour task, using predator and

sexually stimulating motivations rather than familiar objects (Bisazza, Pignatti, & Vallortigara, 1997). The context of a situation may alter which eye an animal may prefer to use. Toads were found to attack prey in their right visual field (ignoring the left visual field) and attack conspecifics in their left visual field (Vallortigara, Rogers, Bisazza, Lippolis, & Robins, 1998). These findings provide information on the evolutionary origins of lateralization in the brain which, in turn, may have implications for the neural representation of numerosity.

Species more closely related to humans than domestic chicks have also shown evidence of a mental number line. Chimpanzees preformed a number sequence task in a study conducted by Adachi (2014). Numbers appeared on a screen in a randomized formation on a grid, and participants were trained to tap each number in increasing order from small to large magnitude. Following training, testing only involved two numbers; 1 and 9. The numbers were displayed horizontally, half of the trials were given 1 on the left and 9 on the right. The other half of trials had the opposite configuration. All chimpanzees were observed in all conditions. The results displayed a faster response in the left to right (1-9) condition compared to the right-left (9-1) condition. This showed a tendency in chimpanzees to more quickly process small numbers in the left visual field and large numbers in the right visual field. This study contradicts the view that the SNARC effect depends on language.

Current Study

The current research will explore the tendency of domestic chicks to use number-space mapping similar to humans' mental number line. The current study attempts to confirm the findings of Rugani, Vallortigara, Priftis, and Regolin (2015) who found a significant SNARC effect in domestic chicks. Given the considerable body of work indicating the role of culture, language, and development on the mental number line in humans, it is important to further

examine this result. The independent variable in my study is number of stimuli on panels during testing. The dependent variables are: the chicks' choice of the left or right stimulus panel; the chicks' choice to move behind either panel from the panel's left or right side; the amount of time spent on the left or right side of the test arena; the total duration of the choice trial.

I hypothesize that domestic chicks do not possess a mental number line and the chicks will not have a left or right side bias in the task. It has been shown that humans' mental number line is influenced by the direction of reading within their language of origins. Domestic chicks do not have a language capacity that could influence such a tendency. Even though evidence in favour of a mental number line in chicks has been provided by Rugani et al., there is reason to conduct further work to confirm this remarkable effect.

Method

Subjects

I observed a total of 19 Brown Leghorn domestic chicks, the same species used by Rugani et al. (2015). The first set of 4 chicks were obtained from Bonnie's Hatchery (Elmira, ON) at 2 days of age. The remaining chicks were incubated and hatched at the Advanced Avian Research Facility (AFAR) at Western University. All subjects were individually housed consistent with Rugani et al. (2015) study. The colony rooms were kept at a constant temperature of 29±1ºC and 68% humidity on a 12: 12 hour light: dark schedule with light onset at 0700h. All animals were treated and tested following appropriate guidelines set by the Canadian Council on Animal Care (CCAC) and under Western University Animal Use Committee approval (see appendix A). Thirteen subjects failed to complete testing, either because they did not consume the mealworm rewards or did not search behind stimulus panels. It is not clear why some subjects did not eat mealworms. Rugani et al. (2015) reported that 25% of their chicks showed

little interest in the food reward and their data were not included in the final sample in Rugani et al.'s study.

Materials

   Apparatus. Subjects were tested one at a time in a diamond-shaped arena 20 cm high, 68 cm long, and 89 cm wide (see appendix B). A transparent rectangular wall (10 cm X 20 cm) was used to confine subjects at the start of each trial. Stimulus panels were attached to white opaque boards (11.5 cm X 9 cm) with Velcro®. All trials were video recorded. A stopwatch was used to record trial duration. Panel choice was rewarded with a mealworm. Small meal worms were obtained from the National Reptile Supply (Millgrove, Ontario).

   Stimuli. White panels (9 X 20 cm) were used with varying arrangements of red squares (1.2 X 1.2 cm) displayed on them. Training trials used 20 stimulus panels with varying arrangements of 5 red squares. Testing trials used two panels of 5 varying arrangements of 2 red squares and two panels of 5 varying arrangements of 8 red squares for a total of 20 testing panels.

Procedure

      For all habituation, training and test trials chicks were deprived of food for 2 hours before observations began. Chicks were not fed between testing trials.

      Habituation Procedure. Habituation consisted of a chick being placed in the apparatus confined by a transparent rectangular wall and watching a mealworm on a string being placed behind a white opaque board. The chick was then released by removing the transparent wall confining it, to retrieve the worm. This was done until successful retrieval occurred 5 consecutive times.

      Training Trials. Training trials consisted of the chick being confined behind the transparent wall and released to find the mealworm hidden behind the stimulus panel. Twenty

trials consisted of 20 different stimulus panels with varying arrangements of 5 red squares

presented on the surface. Once the mealworm was found and eaten the trial was recorded as

successful. Retrieval time was recorded. Chicks had to successfully complete 20 trials before

continuing to testing.

       Testing Procedure. Testing trials consisted of the chick being confined by the

transparent wall and when released, searching for a mealworm behind one of the stimulus panels.

No mealworm was behind the stimulus panels; food reward was given after all choices were

made at the end of the testing. The order of the small and large number testing blocks were

counterbalanced across subjects. Choice was defined as when the head and at least ¾ of the

chick's body had entered the area behind one of the two panels. Each video recording was

viewed twice for each of the analyses. Agreement between the two viewings of each video was

100%. Panel choice, side of panel choice, time spent on each side of the apparatus was recorded

and total trial duration was obtained from the videos. Time spent on the each side of the

apparatus was established by placing transparent overlay on the viewing screen up with a vertical

line corresponding to the centre of the apparatus. Trial duration was the total time from releasing

the chick until the chick chose a panel.

       Habituation, training and testing was done on the same day with a 1 hour break after

familiarization and training and another 1 hour break between testing conditions. The experiment

began when chicks were 3 days old and continued on subsequent days up to 7 days of age. Past 7

days, chicks were no longer suitable for the replication of the previous study (Rugani et al.,

2015) and were too large for the apparatus.

       Data Analysis. Chi-square tests were used to analyze panel and side of panel choices.

McNemar's test was conducted to determine if there were panel or side preferences on the first

trial only. Cochran's Q test was used to determine if panel and side preferences changed over

trials. ANOVA was used to test for differences in the time spent on the left or right side of the

apparatus and for total trial duration.

Results

Panel and Side Choice

The chicks did not display a preference to search behind the left or right panels in the 2

vs. 2 or 8 vs. 8 test condition, $X^2 = 0.67$, $p= 0.795$, *n.s.* Similarly, chicks did not display a

preference to move behind the panels from the left or right side of panels in the 2 vs. 2 or 8 vs. 8

test conditions, $X^2 = 0.67$, $p= 0.795$, *n.s.* As can be seen from table 1, the chi square results are

the same for the panel and side tests because the same numerical values appear (although in

different cells) in the two chi-square tables.

	Panel Choice		Side Choice	
	Left	Right	Left	Right
2 vs. 2	14	16	17	13
8 vs. 8	13	17	16	14

Table 1. Chicks' choice of left or right panel and side of panel.

Panel and side choice on the first trial only

Chicks' first trial only was analyzed with the McNemar test, I was able to determine if the chicks' choice of the left panel occurred more in the 2 vs. 2 condition or 8 vs. 8 condition. The McNemar test is appropriate for dichotomous data with matched pairs of subjects. There was no significant left or right panel preference in 2 vs. 2 or 8 vs. 8 test conditions, $p = 0.500$, *n.s.* There was, similarly, no side of panel preference on the first trial only, $p = 1.00$.

Choice over trials

A Cochran's Q test was conducted in order to see if chicks' choices of the left panel change over trials, Cochran's Q test is an extension of the McNemar test for related samples. There was no significant change over trials on 2 vs. 2 tests $p = .179$, *n.s.*, or 8 vs. 8 tests $p = .132$, *n.s.*

Time on left and right sides of apparatus

It can be seen from figure 1. that, chicks initially displayed a strong left preference in the 2 vs. 2 condition that declined over trials. During the 8 vs. 8 trials the chicks initially showed a strong right preference that also changed over trials

These percentage data were arcsin transformed for analysis. There was no significant difference due to testing condition $F_{1,5} = 0.029$, $p= .872$, n.s. It can be seen from figure 1, that the mean percent time spent by the chicks on the left of the apparatus in the 8 vs. 8 condition (40.457 s) and the 2 vs. 2 condition (40.453 s) is almost identical. There was, similarly, no significant effect of trial, $F_{4, 20} = 1.786$, $p = .171$, n.s. There was, however, a significant interaction between condition and trial $F_{4, 20} = 4.145$, $p = .013$. Chicks initially spent more time on the left in 2 vs. 2 tests and more time on the right in 8 vs. 8 tests, and this preference completely reversed over the course of testing.
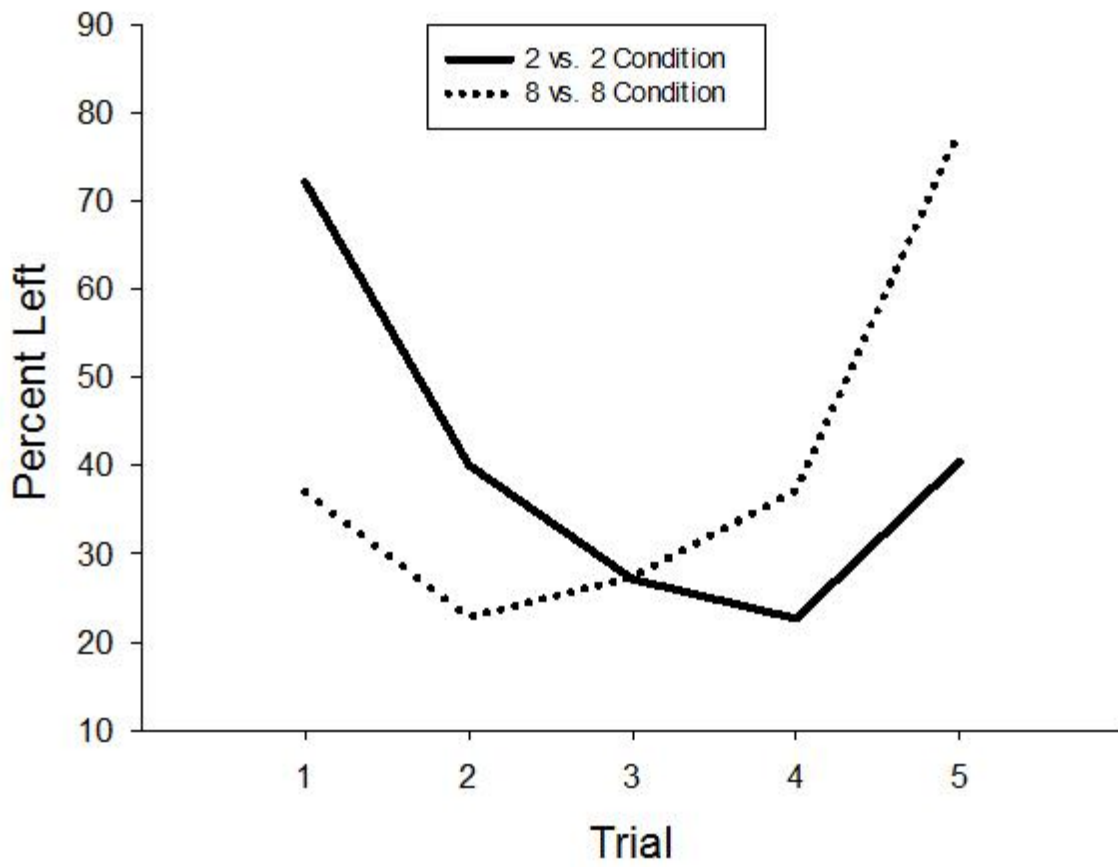
Figure 1. Percent time on the left side of the apparatus during tests.

Trial duration

There was no significant difference in trial duration between test conditions 2 vs. 2 and 8 vs. 8, $F_{1,4} = 0.412$, $p = .549$, n.s. and no significant effect of trial $F_{4,20} = 1.713$, $p = .187$, n.s. There was, however, a significant interaction between condition and trial $F_{4,20} = 3.524$, $p = .025$, $p < .05$. As can be seen from figure 2, trial duration decreased over trials in the 2 vs. 2 but not the 8 vs. 8 condition.
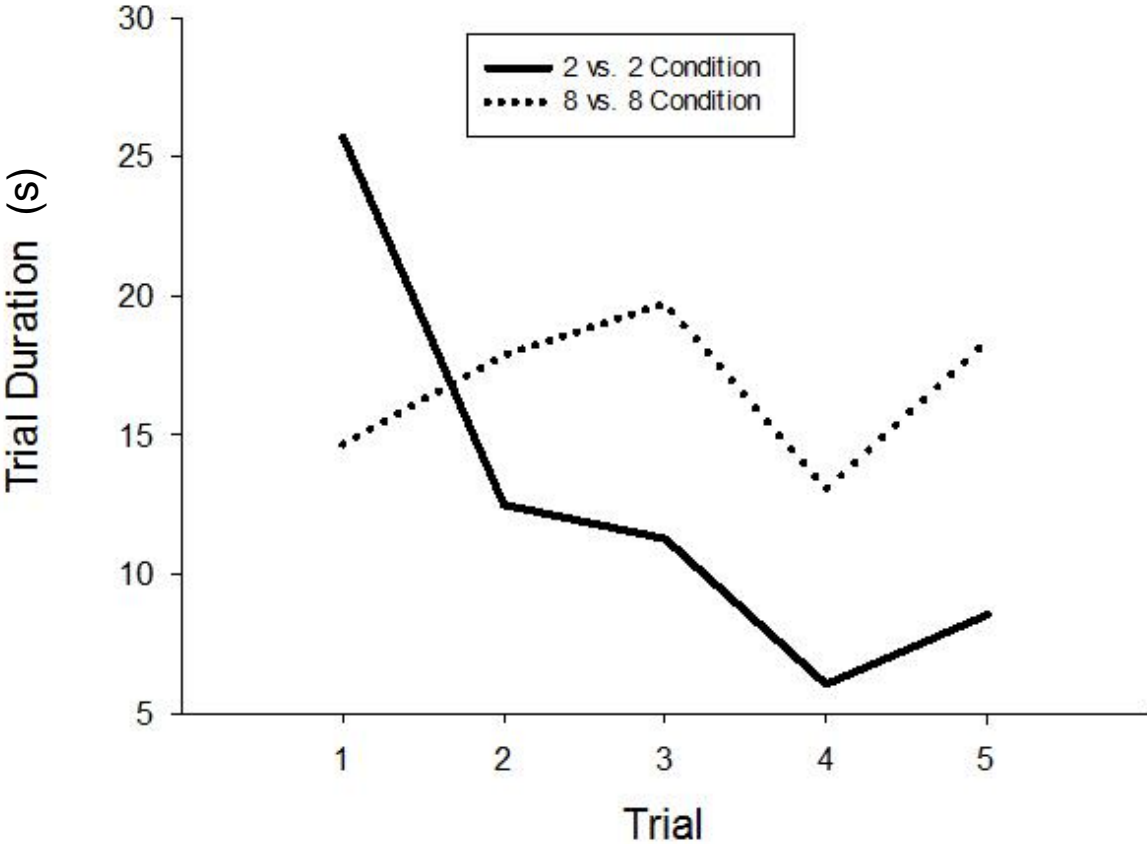
Figure 2. Total trial duration.

Discussion

There was no left or right preference observed for either panel choice or side of panel choice. This was the case for both the first trial and for all trials considered together.

Chicks in the 2 vs. 2 condition spent more time in the left area of the apparatus at the beginning of the trials and this declined over time. In the 8 vs. 8 condition the chicks had an initial preference for the right side of the apparatus. In both conditions, however, these preferences reversed over trials and there was no mean preference for either the left or right side of the arena.

Chicks exhibited a decrease in latency to choose across trials in the 2 vs. 2 condition. It is possible that the chicks learned to differentiate and choose quicker in the small number condition but took longer to decide in the large number condition due to the greater number of stimulus squares present. With more stimuli present, chicks may have taken longer to make a decision.

The mental number line predicts that small numbers are associated with left space whereas large numbers are associated with right space. If this was true for the chicks, their behaviour would display a left panel choice preference in the small number (2 vs. 2) condition and a right panel choice preference in the large number (8 vs. 8) condition. Because the chicks were trained to find a mealworm behind a panel with 5 red squares on it, 2 is a small number, relative to 5 and 8 is a large number.

Numerical Abilities in Birds

The current results indicate that number is not ordered according to the number line (low –to-high, left to right) for young domestic chicks. Numerical abilities have been found, however, in domestic chicks, and a wide variety of avian species. Birds cannot count but they have been shown to perform accurate estimates of number (Scarf, Hayne & Colombo, 2011). Many birds

can recognize configurations of elements and discriminate between them on the basis of number. Chicks were trained to discriminate identical elements as well as similar sets of values when physical variables (spatial distribution, contour length, surface area etc.) were equalized (Rugani, Regolin, & Vallortigara, 2008). It was shown that chicks can differentiate one versus two and two versus three stimulus sets. However, such discrimination does not occur for all numerosity. Chicks were unable to discriminate elements of four versus five, four versus six and three versus four elements (Rugani et al., 2008). Chicks were unable to discriminate between larger numbers however, this leaves further research for a possible mental number line present for smaller numbers, ranging from 1-3.

Pigeons have been found to be able to discriminate large numerical values. Previous research conducted by Roberts et al. (2005) suggested that pigeons can count behavioural responses. Pigeons were trained to peck a white key that was positioned in between a red and green key. On some trials only 1 peck at the white key was necessary for the red and green lights to be illuminated and when the red key was pecked, food reinforcement was given. On other trials the red and green keys were only illuminated after 16 pecks, and the green key needed to be pecked in order for reinforcement to be provided. A variation of the task also included different responses (red vs. green key for reinforcement) for 2 and 32 pecks. Pigeons learned the association and preformed both trainings very well (Roberts et al., 2005). Even though pigeons are able to display discrimination of larger numbers, this does not provide evidence of an ability to associate increasing magnitude from left to right.

Adaptive Value of Numerical Abilities

The ability to differentiate sets of stimuli can be beneficial for the animal as a survival mechanism. Birds may use a number discrimination in the wild to increase fitness related to;

recognition of prey, foraging, laying eggs, nest-building etc. Brown-headed female cowbirds (Molothrus ater) are a species of birds that lay their eggs in 150 different species of host. As a brood parasite they lay eggs in nests that are most beneficial for their reproductive success. It has been shown that such cowbirds can differentiate not only the amount of eggs in the host nest but also the change in the number of eggs over time (White, Ho, & Freed-Brown, 2009). Over the course of 3 days in experimental conditions female cowbirds preferred to lay their eggs in the nest not only that had the most eggs but also the nest which increased in egg quantity over days.

New Zealand robins are able to differentiate between expected and unexpected mathematical changes in food items (Garland & Low, 2014). Robins increase search time and display greater pecking behaviour when there is a violation of expected food quantity. When addition and subtraction of food values did not match the trained mathematical changes, such behavioral responses occurred (Garland & Low, 2014). Domestic chicks have also been shown to use a specific eye (left or right) preference for searching, depending on novel or familiar stimuli (Vallortigara, 2000). There are obvious benefits of change detection, of which change quantity is one of them. Different mechanisms are used by the birds in the wild depending on the familiarity or unfamiliarity of an event. The ability to detect change in quantity may be helpful for discriminating and quantifying prey and/or food sources in the wild

Brain Structures Associated with Numerosity

Avian species do not possess the brain structures that are associated with counting in humans. This may explain the inability of chicks to demonstrate a mental number line. Both the pre-frontal and parietal cortex are major structures related to counting / number abilities in humans and non-human primates (Droit-Volet, & Coull, 2015). There are specific neurons in the brain of both humans and non-human primates for the use of numbers (Ditz & Nieder, 2015). In

birds the nidopallium caudolaterale (NCL) performs number related functions similar to those of

the neurons found in the pre-frontal and parietal cortex of humans. Previous research on crows

detected neurons that respond selectively to the number of items within a sample (Ditz & Nieder,

2015). Neurons discriminated for the numbers 1,2,3,4 or 6 in a sample. The crows do not exhibit

a mental number line but rather a "labelled-line coding". This is explained by certain neurons

firing for particular numbers. For example, a neuron may fire for the value of 4 elements in a

sample regardless of colour, shape, surface area, size etc., and each value may be represented by

different neurons firing within the brain. Animals with brain structures that correspond more

closely to humans show stronger evidence of a mental number line. Non-human primates have

displayed a mental-number line which may be in accordance with the brain structures similar to

humans. Chimpanzees are able to perform a number sequence task (Adachi, 2014). Numbers

appeared on a screen in a randomized formation on a grid, and participants were trained to tap

each number in increasing order from small to large magnitude (Adachi, 2014).

Analysis of Rugani et al. (2015)

The absence of supporting background literature for the existence of a mental number

line in domestic chicks encourages scepticism of Rugani et al.'s (2015) results. Even though the

previous study showed a mental number line in domestic chicks the power of the analyses does

not justify such a strong claim. Rugani et al. (2015) relied on single-sample *t*-tests evaluating

against a null hypothesis (no preference left or right choice) of 0.5 (50% left, 50% right) for all

comparisons. By using such a criterion the bias was present in most chicks. However, if a more

strict criterion of ≥ 70% choices of a single side was applied 63.6% of chicks had a bias

rightward (Harshaw, 2015). Such a bias inflated the chicks mental number line results in the 8

vs. 8 condition. Thus, the statistical analyses conducted by Rugani et al. were insufficient to

provide reliable evidence of a mental number line in chicks. The current study conducted a greater number of tests for stronger results.

Further Testing

To further pursue the research question of the current study additional experiments can be conducted. It would be beneficial to increase the sample size. Due to the seasonality of local farmers it became difficult to acquire chicks in the winter months. As well, when incubating eggs in the laboratory the amount of chicks within each set varied. It was difficult to predict the number of chicks that would reach full maturity and hatch. It would also be useful to design the task such that all chicks that were tested completed the experiment. The current study had 6 chicks perform the task of an $n = 19$. The 68.42% of chicks that failed to perform the task were not included in the final sample. Rugani et al. (2015) faced similar trouble. Their experiment consisted of an $n = 15$ with 25% of the chicks not performing the task. In addition to running the experiment replicated in the current study, Rugani et al. (2015) conducted subsequent experiments using varied stimuli. The perimeter, surface area, size, and colour of the stimuli panels were altered. Similar testing was planned for the current study, but due to the lack of support for a mental number line, no further testing was required.

A further extension of the current study and previous literature would be to test the chicks on a basic numerical discrimination task, rather than searching for a mental number line. It would be of interest to see if chicks as young as 3 days old (consistent with Rugani et al., 2015) are able to discriminate a value of 5 from 8 and 2. The chicks would be trained to associate searching for food behind the larger quantity stimulus with a food reward. This would test the basic assumptions of the mental number line research.

The current study was able to confirm the unreliability of Rugani et al. (2015) and extend research on the numeric abilities of domestic chicks. The ability to discriminate between values seen in avian species allows for the understanding of how this is beneficial to survival in the wild. As well, this helps unravel the mechanisms of numerosity in the brain. Overall, the current study found results consistent with the original hypothesis, disproving the results of Rugani et al. (2015). Chicks do not display a mental number line similar to that shown in humans, which is influenced by culture and reading-direction.

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Appendix A

Western

AUP Number: 2015-019
PI Name: Sherry, David
AUP Title: Cognition, Behavior, And The Brain Of Birds.
Approval Date: 10/20/2015

Official Notice of Animal Use Subcommittee (AUS) Approval: Your new Animal Use Protocol (AUP) entitled "Cognition, Behavior, And The Brain Of Birds." has been APPROVED by the Animal Use Subcommittee of the University Council on Animal Care. This approval, although valid for four years, and is subject to annual Protocol Renewal.2015-019::1

1. This AUP number must be indicated when ordering animals for this project.
2. Animals for other projects may not be ordered under this AUP number.
3. Purchases of animals other than through this system must be cleared through the ACVS office. Health certificates will be required.

The holder of this Animal Use Protocol is responsible to ensure that all associated safety components (biosafety, radiation safety, general laboratory safety) comply with institutional safety standards and have received all necessary approvals. Please consult directly with your institutional safety officers.

Submitted by: Copeman, Laura
on behalf of the Animal Use Subcommittee
University Council on Animal Care

Appendix B
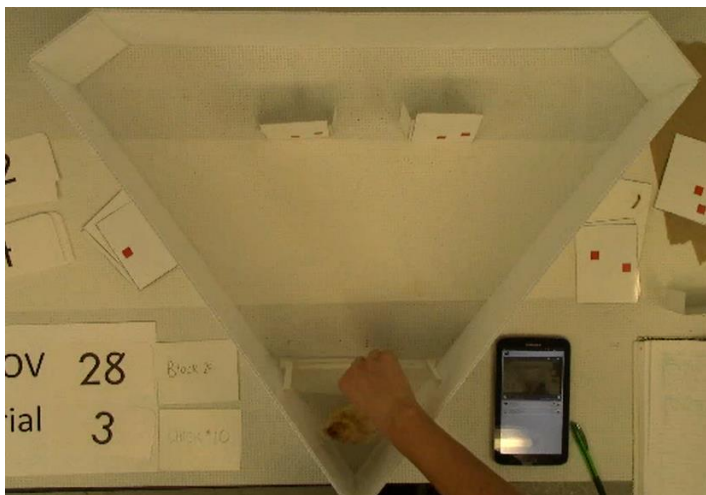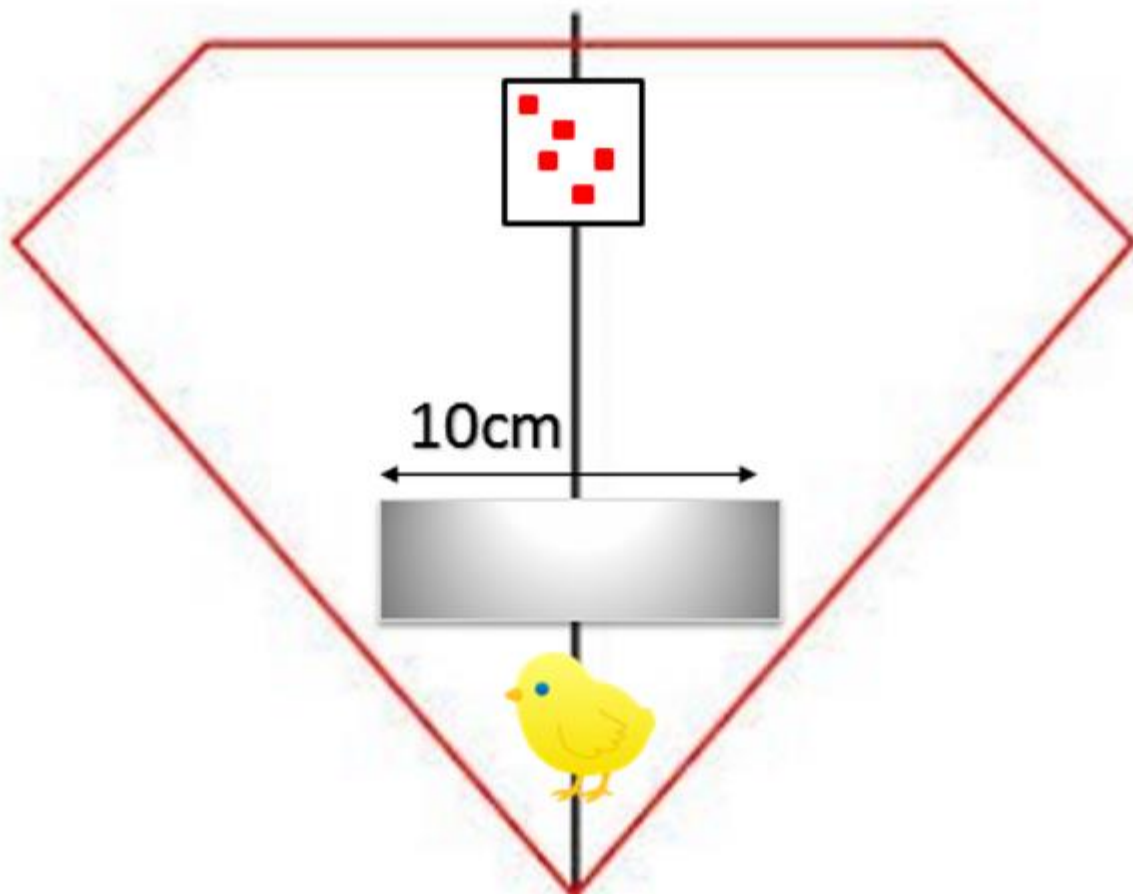
Upper drawing shows the training and testing apparatus. Lower photographs show a 2 vs. 2 test (left) and an 8 vs 8 test (right).