Author for correspondence:
Justin N. Wood
e-mail: justin.wood@usc.edu

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The development of newborn object recognition in fast and slow visual worlds

Justin N. Wood and Samantha M. W. Wood

Department of Psychology, University of Southern California, Los Angeles, CA 90089, USA

Object recognition is central to perception and cognition. Yet relatively little is known about the environmental factors that cause invariant object recognition to emerge in the newborn brain. Is this ability a hardwired property of vision? Or does the development of invariant object recognition require experience with a particular kind of visual environment? Here, we used a high-throughput controlled-rearing method to examine whether newborn chicks (*Gallus gallus*) require visual experience with slowly changing objects to develop invariant object recognition abilities. When newborn chicks were raised with a slowly rotating virtual object, the chicks built invariant object representations that generalized across novel viewpoints and rotation speeds. In contrast, when newborn chicks were raised with a virtual object that rotated more quickly, the chicks built viewpoint-specific object representations that failed to generalize to novel viewpoints and rotation speeds. Moreover, there was a direct relationship between the speed of the object and the amount of invariance in the chick's object representation. Thus, visual experience with slowly changing objects plays a critical role in the development of invariant object recognition. These results indicate that invariant object recognition is not a hardwired property of vision, but is learned rapidly when newborns encounter a slowly changing visual world.

1. Introduction

To perceive the world successfully, newborn animals must perform a difficult task: they must build abstract object representations from high-dimensional sensory inputs, and use those representations to generalize past experience to new viewing situations. This ability is known as 'invariant object recognition'. Despite the computational difficulty of this task [1], many animals develop invariant object recognition abilities, including primates [2–6], rodents [7–9] and birds [10–14]. For example, after just a brief glimpse of an object, human adults can recognize objects across novel changes in viewpoint, scale, retinal position and lighting conditions [3]. To date, however, the development of invariant object recognition is poorly understood. Although previous studies have shown that invariant object recognition can develop rapidly in newborn visual systems [12–14], these findings do not reveal the environmental factors that cause this ability to emerge in the brain. Is invariant object recognition a hardwired property of vision? Or does the development of invariant object recognition require experience with a particular kind of visual environment?

According to temporal learning models from computational neuroscience and computer vision, invariant object representations are learned from experience with the spatio-temporal statistics of the natural visual world [15–20]. In particular, researchers have argued that visual systems create invariant object representations by extracting slowly changing features from the visual environment [15,21–23]. The overarching logic of this learning process is as follows: during natural visual experience, the environment tends to change slowly (i.e. objects are typically present for seconds or longer), whereas the primary sensory signal changes rapidly (i.e. individual retinal receptors change on a timescale of milliseconds). Thus, neural mechanisms that extract slowly varying features from quickly varying input signals should create stable representations of the external causes of the sensory input. In support of this view, a variety of computational studies indicate that experience with a natural (slow) visual environment

plays an important role in the development of vision. For example, algorithms that extract slowly varying features from quickly varying input signals can successfully explain the self-organization of complex-cell receptive fields [24], the recognition of whole objects invariant to spatial transformations [25] and the self-organization of place cells, grid cells and head-direction cells [26,27].

In this study, we used a controlled-rearing method to test whether newborn animals need experience with a slowly changing visual environment in order to create invariant object representations. If the environment changes too quickly (and features do not vary slowly), then newborn visual systems might have difficulty building invariant object representations from sensory input. To test this hypothesis, we raised newborn subjects in strictly controlled environments that contained no objects other than a single virtual object. This virtual object rotated continuously at a slow, medium or fast speed. After one week of exposure to this object, we tested whether each subject's object representation could generalize to novel viewpoints (experiment 1) and to novel viewpoints and rotation speeds (experiment 2). If newborns need experience with slowly changing objects to build invariant object representations, then the subjects should successfully build invariant representations only when raised in environments that contain a slowly rotating object. Critically, we studied the *first* visual object representation built by newborn subjects, before their visual systems had been shaped by any prior visual object experience.

Because this experiment required controlling all of the subjects' visual object experiences from the onset of vision, we used a controlled-rearing approach with a newborn animal model: the domestic chick (*Gallus gallus*). Newborn chicks are an ideal animal model for studying the development of vision, for several reasons. First, chicks develop object recognition abilities rapidly—for example, chicks can build a viewpoint-invariant representation of the first object they see in their life [12–14]. Second, chicks can be raised in strictly controlled environments (i.e. environments devoid of objects and caregivers) from the onset of vision.[1] This makes it possible to control all of the chicks' visual object experiences [32,33]. Third, chicks imprint to objects seen soon after hatching; this naturally occurring behaviour can be used to test object recognition abilities without training [34]. Fourth, avian and mammalian brains process sensory input using homologous cortical circuits with similar connectivity patterns [35]. Because birds and mammals use common neural mechanisms to perceive the world, controlled-rearing studies of newborn chicks may inform our understanding of the development of object recognition in both birds and mammals.

2. Experiment 1

(a) Methods

(i) Subjects

Twenty-six domestic chicks of unknown sex were tested. No subjects were excluded from the analyses. The sample sizes were determined before the experiments were conducted based on previous high-throughput controlled-rearing experiments with newborn chicks [12–14]. The chicks were randomly assigned to the conditions. The eggs were obtained from a local distributor and incubated in darkness in an OVA-Easy incubator (Brinsea Products Inc., Titusville, FL). The incubation
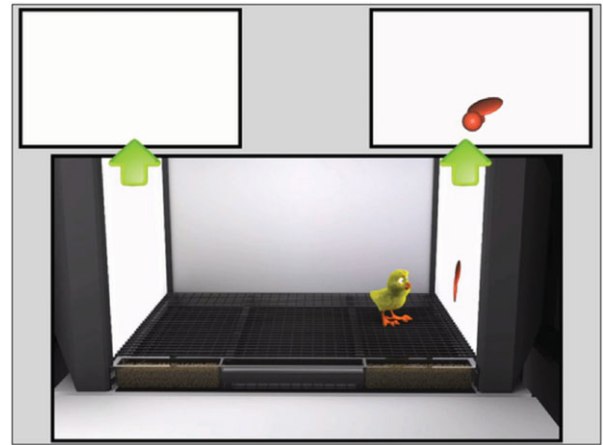
Figure 1. Illustration of a controlled-rearing chamber. Newborn chicks were raised in strictly controlled environments devoid of real-world objects. To present object stimuli to the chicks, virtual objects were projected on two display walls situated on opposite sides of the chamber. During the input phase (first week of life), the chicks were exposed to a single virtual object that rotated continuously, completing a full rotation every 1 (fast speed), 5 (medium speed) or 15 s (slow speed). (Online version in colour.)

room was kept in complete darkness. After hatching, the chicks were moved from the incubation room to the controlled-rearing chambers in darkness with the aid of night vision goggles. Each chick was raised singly within its own chamber. These experiments were approved by The University of Southern California Institutional Animal Care and Use Committee.

(ii) Controlled-rearing chambers

We raised newborn chicks in specially designed controlled-rearing chambers (figure 1) that provided complete control over all visual object experiences. The chambers were devoid of all real-world (solid, bounded) objects. Each chamber measured 66 cm (length) × 42 cm (width) × 69 cm (height) and was constructed from white, high-density polyethylene. Food and water were provided within transparent troughs in the ground that measured 66 cm (length) × 2.5 cm (width) × 2.7 cm (height). The floors were wire mesh and supported 2.7 cm off the ground by thin, transparent beams.

Object stimuli were presented to the chick by projecting virtual objects on two display walls (LCD monitors) situated on opposite sides of the chamber. The display walls were 19″ LCD monitors (1440 × 900 pixel resolution). On average, the virtual objects measured 8 cm (length) × 7 cm (height) and were suspended 3 cm off the floor. The objects were displayed on a uniform white background at the middle of the display walls. The virtual objects presented in this study can be viewed in electronic supplementary material, movies S1–S5.

The chicks' behaviour was tracked by microcameras in the ceilings of the chambers and image-based tracking software (EthoVision XT, Noldus Information Technology, Leesburg, VA) that calculated the amount of time the subject spent within zones (22 × 42 cm) next to the left and right display walls. We recorded all of the chicks' behaviour (nine samples per second, 24 h per day, 7 days per week) across the duration of the two-week experiment. This high-throughput data collection approach made it possible to measure each newborn chick's first visual object representation with high precision. In total, 8736 h of video footage (14 days × 24 hours per day × 26 subjects) were collected for experiment 1.

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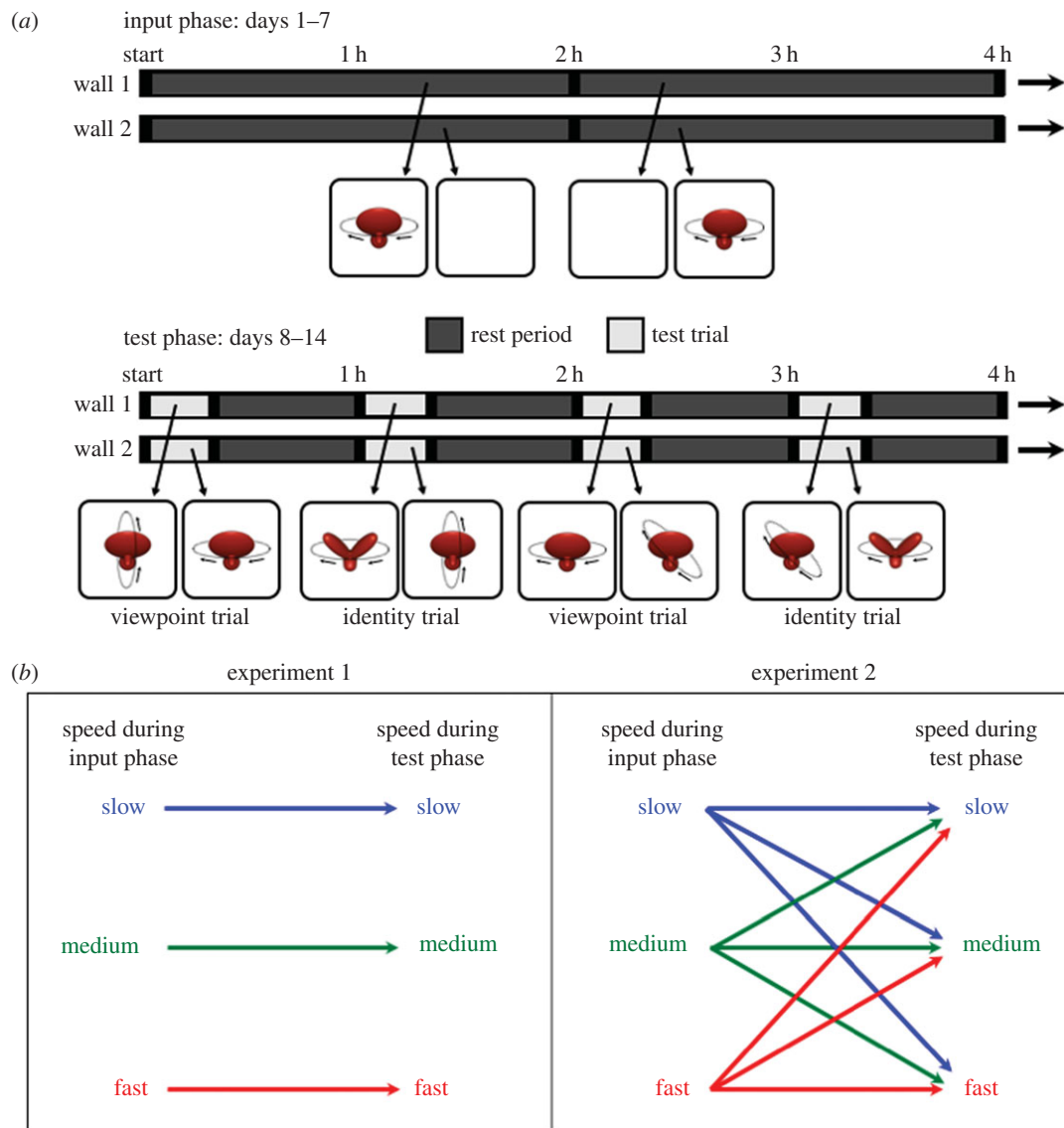
Figure 2. The experimental procedure. (*a*) A schematic showing a 4 h presentation schedule of the virtual objects during the input phase and test phase. During the input phase, chicks were exposed to a single virtual object. During the test phase, we measured each chick's sensitivity to object identity features (identity trials) and viewpoint features (viewpoint trials). (*b*) The rotation speeds of the virtual objects during the input phase and test phase. In experiment 1, the objects rotated at the same speed during the input phase and test phase. In experiment 2, the objects rotated at slow, medium and fast speeds on different test trials during the test phase. (Online version in colour.)

(iii) Procedure

During the input phase (first week of life), newborn chicks were raised in environments that contained a single virtual object rotating around a single axis. The object rotated at different speeds for different subjects, completing a 360° rotation around a frontoparallel vertical axis every 1 (fast speed), 5 (medium speed) or 15 s (slow speed). The animations are presented in electronic supplementary material, movies S1–S3. The object appeared for an equal amount of time on the left and right display walls, switching walls every 2 h. The virtual objects were modelled after those used in previous studies that tested for invariant object recognition in adult rats [7,8] and newborn chicks [12–14]. Half of the chicks were imprinted to each of the two objects, with the other object serving as the novel object.

During the test phase (second week of life), we measured each chick's sensitivity to viewpoint features and identity features. We measured sensitivity to these two feature types, because building an invariant object representation requires transforming patterns of retinal activity (viewpoint features) into a higher-level representation that is tolerant to retinal

image changes and selective for a particular object (identity features). Thus, measuring sensitivity to viewpoint features and identity features reveals how successful the chick has been in building an invariant representation. If the chick has high sensitivity to identity features and low sensitivity to viewpoint features, then the chick successfully built an invariant object representation (i.e. a representation that is selective for the object's identity and tolerant to retinal image variation). Conversely, if the chick has high sensitivity to viewpoint features and low sensitivity to identity features, then the chick failed to build an invariant object representation.

Figure 2*a* illustrates the testing schedule and the trial types. On the viewpoint trials, one display wall showed the imprinted object rotating around the familiar axis (which presented familiar viewpoints of the object), whereas the other display wall showed the imprinted object rotating around a novel axis (which presented novel viewpoints of the object; see electronic supplementary material, movie S4 for sample animations). If the chicks built object representations that contained viewpoint features, then they should have preferred the
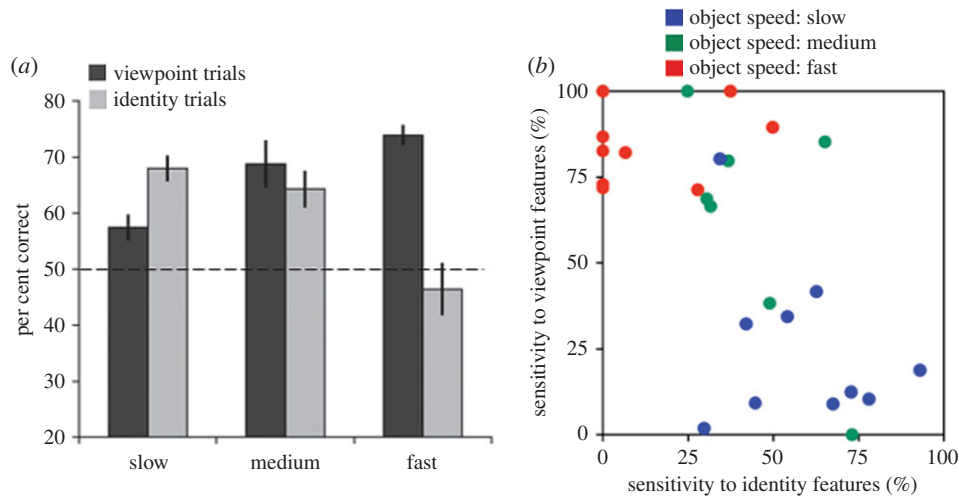
Figure 3. Results from experiment 1. (*a*) The chicks' object recognition performance when raised with a slow, medium or fast object. The graph shows the percentage of time the chicks spent with the correct animation (i.e. the familiar object on the identity trials and the familiar viewpoint range on the viewpoint trials). When exposed to a slowly rotating object, the chicks built invariant representations that were selective for object identity and tolerant to changes in viewpoint. In contrast, when exposed to a quickly rotating object, the chicks built viewpoint-specific representations that were selective for familiar viewpoints with little to no sensitivity for object identity features. (*b*) The abstraction space for visualizing the pattern of variation across subjects. Each dot depicts the object representation built by a single chick. The *x*-axis reflects the representation's sensitivity to identity features and the *y*-axis reflects the representation's sensitivity to viewpoint features. The position of the representation in the abstraction space was largely determined by the object's rotation speed.

object rotating around the familiar axis compared with the novel axis.

On the identity trials, one display wall showed the imprinted object rotating around a novel axis, whereas the other display wall showed a novel object rotating around the familiar axis (see electronic supplementary material, movie S5 for sample animations). Importantly, this comparison equated the between-object image difference (i.e. the image-level difference between the test animation of the novel object and the input animation of the imprinted object) and the within-object image difference (i.e. the image-level difference between the test animation of the imprinted object and the input animation of the imprinted object), on both pixel-like and V1-like levels (for details, see electronic supplementary material, figures S1 and S2). Thus, to recognize their imprinted object on the identity trials, the chicks needed to build invariant representations that were selective for the object's identity and tolerant to identity-preserving image transformations (i.e. changes in viewpoint). The chicks received 24 test trials per day (168 test trials in total), at the rate of one trial per hour. Each test trial lasted 20 min. For each chick, the objects in the test phase rotated at the same speed as the object in the input phase.

(b) Results

To compute each chick's object recognition performance, we first computed the proportion of time each chick spent with the correct animation compared with the incorrect animation for the test trials in which the imprinted object switched display walls after the rest period and for the test trials in which the imprinted object stayed on the same display wall after the rest period. We then computed the average of these two values to obtain a single recognition performance score for each chick in the condition.

The results are shown in figure 3*a*. An ANOVA with the within-subject factor of trial type (viewpoint trials versus identity trials) and the between-subject factor of object speed (slow,

medium, fast) revealed a significant main effect of trial type ($F_{1,23} = 7.07$, $p = 0.01$, $\eta_p^2 = 0.24$) and a significant interaction between trial type and object speed ($F_{2,23} = 18.75$, $p < 0.001$, $\eta_p^2 = 0.62$). When raised with a slowly rotating object, newborn chicks built viewpoint-invariant object representations that were more sensitive to identity features than viewpoint features (two-tailed *t*-tests, $t_9 = 3.01$, $p = 0.02$, Cohen's $d = 0.95$). Conversely, when raised with a quickly rotating object, newborn chicks built viewpoint-specific object representations that were more sensitive to viewpoint features than identity features (two-tailed *t*-tests, $t_8 = 5.23$, $p = 0.001$, Cohen's $d = 1.74$). The chicks raised with the medium speed object built representations that were equally sensitive to identity features and viewpoint features (two-tailed *t*-tests, $t_6 = 0.86$, $p = 0.42$, Cohen's $d = 0.32$).

To visualize this pattern of variation, we charted the position of each chick's object representation within a two-dimensional abstraction space[2] (figure 3*b*; each point represents the object representation built by one chick). The *x*- and *y*-axis reflect the object representation's sensitivity to identity features and viewpoint features, respectively. Thus, the position of the representation within the abstraction space reflects its degree of abstraction (i.e. the representation's sensitivity to identity features and tolerance to changes in viewpoint).

The chicks exposed to a slowly rotating object tended to build abstract object representations that were sensitive to identity features but not viewpoint features (the representations occupying the bottom right area of the abstraction space). In contrast, the chicks exposed to a quickly rotating object built viewpoint-specific object representations that were sensitive to viewpoint features but not identity features (the representations occupying the top left area of the abstraction space). These results show that newborn chicks can build many different types of object representations, with the degree of abstraction varying largely as a function of the object's rotation speed.

In experiment 1, the objects moved at the same speed during the input phase and test phase. Accordingly, the effect of rotation speed on object recognition performance could be
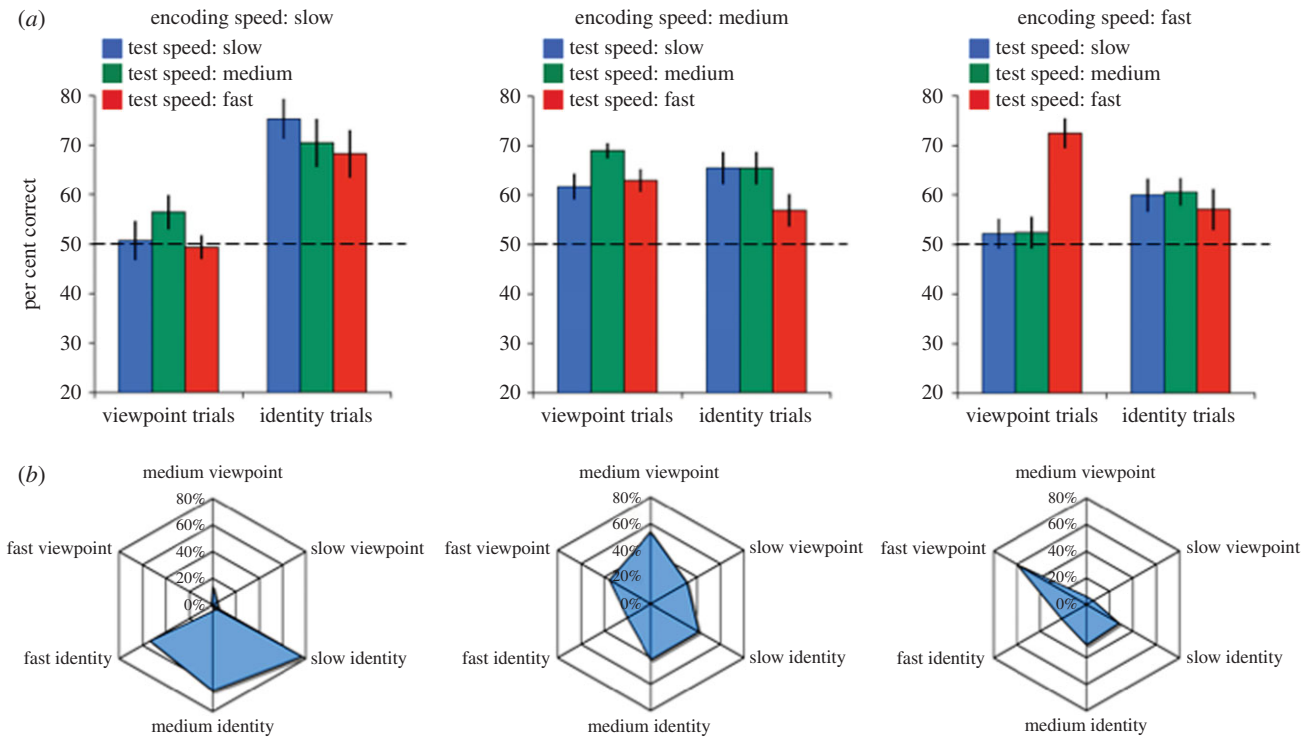
Figure 4. Results from experiment 2. (*a*) The chicks' object recognition performance when raised with a slow, medium or fast object. The graphs show the percentage of time the chicks spent with the correct animation for each test trial type. (*b*) Radar graphs illustrate the different types of object representations built by the chicks exposed to the slow, medium and fast objects during the input phase. The information content of the representation was largely determined by the object's rotation speed when the object was encoded into memory. When exposed to a slowly rotating object, the chicks built invariant representations that were selective for object identity, regardless of whether the test objects rotated at slow, medium or fast speeds. In contrast, when exposed to a quickly rotating object, the chicks built viewpoint-specific representations that were selective for familiar spatio-temporal features.

explained by limitations in chicks' ability to perceive and/or attend to quickly rotating objects, rather than limitations in chicks' ability to build (encode) visual object representations. To examine whether the faster rotation speeds in experiment 1 disrupted processes related to perception and attention, we performed a second experiment in which all of the chicks were tested with objects that rotated at slow, medium and fast speeds. If the faster rotation speeds disrupted processes related to perception or attention, then recognition performance should be low when the test objects rotate at fast speeds (because the chicks would be unable to perceive and/or attend to quickly rotating objects if the fast rotation speed exceeds the limitations of chicks' perception or attention abilities). Conversely, if the faster rotation speeds disrupted processes related to encoding visual object representations, then recognition performance should be high whether the test objects rotate at slow, medium or fast speeds—provided that the object rotated slowly when being encoded into memory.

3. Experiment 2

(a) Methods

Experiment 2 was identical to experiment 1, with two key changes. First, a new group of 34 domestic chicks of unknown sex was tested. Second, rather than being presented with test objects that rotated at the same speed as the input object, the test objects rotated at slow, medium and fast speeds on different test trials (figure 2*b*). In total, 11 424 h of video footage (14 days × 24 hours per day × 34 subjects) were collected for experiment 2.

(b) Results

The results are shown in figure 4*a*. An ANOVA with the within-subject factor of trial type (slow viewpoint trials, medium viewpoint trials, fast viewpoint trials, slow identity trials, medium identity trials and fast identity trials) and the between-subject factor of encoding speed (slow, medium, fast) revealed a significant main effect of trial type ($F_{5,155} = 7.47$, $p < 0.001$, $\eta_p^2 = 0.19$) and a significant interaction between trial type and encoding speed ($F_{10,155} = 8.75$, $p < 0.001$, $\eta_p^2 = 0.36$).

When newborn chicks were raised with a slowly rotating object, they built invariant object representations that were highly sensitive to identity features, regardless of whether the test objects rotated at slow, medium or fast speeds. In contrast, when newborn chicks were raised with a quickly rotating object, they built viewpoint-specific object representations that were primarily sensitive to familiar spatio-temporal features (i.e. the same images presented at the same speed). Thus, to build a robust invariant representation, chicks require slow visual object input; however, once the object representation has been built, the chick can then recognize the object whether it moves at a slow, medium or fast speed. These results show that the effect of rotation speed on object recognition performance obtained in experiment 1 cannot be explained by appealing to limitations in perception and attention.[3] Rather, faster rotation speeds appear to primarily disrupt chicks' ability to build invariant object representations.

The results from experiment 2 also demonstrate that visual representations in the newborn brain are highly plastic and can take a variety of forms. These forms can be visualized in the six-dimensional radar graphs shown in figure 4*b* (each dimension of the graph reflects the chicks' performance

on one of the six test trial types). More generally, experiment 2 replicates the main findings from experiment 1, and provides additional evidence that it is possible to systematically manipulate the abstract form of a newborn chick's first visual object representation simply by manipulating the object's rotation speed when the object is being encoded into memory.

(c) Measuring the strength of the imprinting response

Did the chicks imprint more strongly to the slowly rotating objects than the quickly rotating objects? To examine whether object speed influenced the strength of the imprinting response, we analysed the proportion of time chicks spent by their imprinted object during the rest periods. During the rest periods, the imprinted object appeared on one display wall and a white screen appeared on the other display wall. In experiment 1, when raised with the slow, medium and fast objects, chicks spent 81% (s.e.m. = 1%), 81% (s.e.m. = 3%) and 77% (s.e.m. = 2%) of their time with the imprinting stimulus, respectively. In experiment 2, when raised with the slow, medium and fast objects, chicks spent 83% (s.e.m. = 2%), 86% (s.e.m. = 1%) and 88% (s.e.m. = 1%) of their time with the imprinting stimulus, respectively. These values did not differ significantly from one another for experiment 1 (one-way ANOVA, $F_{2,23} = 1.23$, $p = 0.31$) or experiment 2 ($F_{2,31} = 1.96$, $p = 0.16$). The chicks imprinted equally strongly to the virtual object, regardless of whether the object rotated at a slow, medium or fast speed. Thus, the faster rotation speeds primarily disrupt the *generative* capacity of visual representations (i.e. the extent to which the representation can generalize to novel viewing situations), not the strength of the imprinting response.

4. Discussion

We used a high-throughput controlled-rearing method with newborn chicks to examine whether the development of invariant object recognition requires visual experience with slowly changing objects. Newborn chicks were able to create a viewpoint-invariant and speed-invariant representation of the first object they encountered in their life, provided that the object rotated slowly when being encoded into memory. However, when newborn chicks were raised with an object that rotated more quickly, the chicks built viewpoint-specific object representations that were selective for familiar spatio-temporal features and failed to generalize across novel viewpoints and rotation speeds. These results support three primary conclusions.

First, this study provides evidence for a 'slowness constraint' on the development of invariant object recognition in a newborn animal. All of the chicks built object representations, but only the chicks exposed to a slowly rotating object successfully built invariant representations that generalized across novel viewpoints and rotation speeds. Thus, newborn chicks need experience with slowly changing objects to create invariant object representations. These results support previous studies showing that adult visual systems extract slowly changing features from the environment to create invariant object representations [15,21–23] and extend this literature by demonstrating that newborn visual systems use a similar strategy to develop invariant object recognition abilities.

These findings do not necessarily imply that newborn chicks build three-dimensional geometrical representations of whole objects when exposed to slowly rotating objects. Chicks could have succeeded on the identity trials by building invariant representations of subfeatures that are smaller or less complex than the entire object. These feature detectors might respond to only a portion of the object, or be sensitive to key two-dimensional, rather than three-dimensional, features. In fact, many leading computational models of invariant object recognition in humans and monkeys explicitly rely on such subfeatures [36–38]. Importantly, regardless of the specific nature of these features, our results indicate that invariant features are learned only when newborn chicks are exposed to slowly changing objects.

Second, these results show that visual object representations in the newborn brain are highly plastic. When exposed to a slowly rotating object, the chicks built abstract representations that were selective for object identity and tolerant to identity-preserving image changes; conversely, when exposed to a quickly rotating object, the chicks built viewpoint-specific representations that were selective for familiar spatio-temporal features. Thus, it is possible to systematically manipulate the abstract form of a newborn chick's first visual object representation simply by varying the object's rotation speed when it is being encoded into memory.

In the cognitive sciences, it is common to interpret early emerging abilities as evidence for hardwired abilities. The present results indicate that, for the domain of object recognition, this may be an incorrect assumption. Newborn chicks develop invariant object recognition abilities rapidly (within the first week of life), but this ability does not emerge automatically. Rather, invariant recognition emerges when newborn chicks are exposed to slowly changing objects. This finding adds to a growing body of research suggesting that invariant object recognition depends upon experience [3,15,16,18,23].

It is important to emphasize that the chicks raised with a quickly rotating object did not perform poorly in all of the conditions. In fact, when the task required remembering the specific spatio-temporal features that were present when the object was encoded into memory (viewpoint trials), the chicks raised with a quickly rotating object significantly outperformed the chicks raised with a slowly rotating object. Thus, exposing newborns to fast visual objects does not simply break vision in general. Rather, experience with fast visual objects disrupts newborn chicks' ability to build invariant object representations.

Third, these results demonstrate that this high-throughput controlled-rearing method can measure—with high precision—how specific visual inputs relate to specific behavioural outputs in a newborn visual system. This opens up experimental avenues for drawing causal links between the particular visual experiences encountered by a newborn and the contents of their mental representations. By systematically manipulating the visual inputs provided to a newborn and observing the effects of those manipulations on behaviour, it is possible to distinguish the experiences that are causally related to behavioural change from those that are not.

To what extent do these findings apply to the development of object recognition in other species such as humans? While this study was not designed to address this question, there is growing evidence in the neurosciences for an evolutionarily

ancient cortical circuit for processing sensory input [35]. Specifically, the six-layered mammalian cortex and avian cortex contain similarities on the cellular [39], molecular [40], connectivity [41] and information-coding levels [42]. This circuit is believed to have evolved in stem amniotes at least 100 million years ago [43] and to underlie the computations used for visual object recognition [3]. If birds and mammals share homologous cortical circuits for processing visual input, as these studies suggest, then controlled-rearing studies of newborn chicks would provide insights into the development of object recognition in mammals. Of course, we might also expect some differences in the development of object recognition across species, especially between chickens and humans. For instance, humans have much larger visual systems than chickens, which may allow humans to achieve greater levels of abstraction across the successive levels of the visual cortex [36,37,44]. Further, chickens, unlike humans, are mobile from birth and immediately able to explore their environment. Such active motor exploration might play an important role in the development of object recognition [45–47].

In sum, this study provides evidence for a slowness constraint on the development of invariant object recognition in a newborn animal. Visual experience with slowly changing objects appears to play a critical role in the development of invariant object recognition. More generally, this study provides evidence that invariant object recognition is not a hardwired property of vision but is learned rapidly when newborns encounter a slowly changing visual world.

Ethics. This study used domestic chicks (*Gallus gallus*) that were reared in specially designed controlled-rearing chambers. We performed non-invasive monitoring of the chicks' behaviour. All prevailing local, national, and international regulations and conventions, and normal scientific ethical practices have been respected.

Data accessibility. The data supporting this article are available as electronic supplementary material.

Endnotes

[1]Previous studies have investigated the effects of visual deprivation on object and face recognition in primates and rodents [28–31]. In these studies, however, the subjects had experience with objects and/or agents (e.g. caregivers) during their lifetime, and these experiences might have shaped their recognition abilities in important ways. In contrast, newborn chicks can be raised in strictly controlled environments (i.e. environments devoid of all objects and caregivers) from the onset of vision. Thus, with chicks, it is possible to examine how patterned visual input affects the development of object recognition at the beginning of life, in the absence of visual experience with natural, real-world objects.

[2]To calculate the position of each chick's representation within the abstraction space (figure 3b), we computed the proportion of time each chick spent with the correct animation compared with the incorrect animation for the identity trials and the viewpoint trials. These values were then scaled to fit on the two axes, such that 0% marked chance performance and 100% marked perfect performance. Perfect performance was equal to each chick's performance on the rest periods, which measured the amount of time the chicks generally preferred to spend in proximity to their imprinted object. This same approach was used to create the radar graphs for experiment 2 (figure 4b).

[3]These results also rule out the possibility that quickly rotating objects are more difficult to recognize than slowly rotating objects in these virtual environments (e.g. owing to distortion effects that may occur when images of three-dimensional objects are projected on a two-dimensional screen). Performance was nearly identical whether the test objects rotated at slow, medium or fast speeds, provided that the chicks were raised with a slowly rotating object.

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