

## RESEARCH ARTICLE

# The role of task difficulty in directing selective attention in bobwhite quail (*Colinus virginianus*) neonates: A developmental test of the intersensory redundancy hypothesis

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## Abstract

The dynamics of selective attention necessarily influences the course of early perceptual development. The intersensory redundancy hypothesis proposes that in early development information presented redundantly across two or more senses selectively recruits attention to the amodal properties of an object or event. In contrast, information presented to a single sense enhances attention to modality-specific properties. The present study assessed the second of these predictions in neonatal bobwhite quail (*Colinus virginianus*), with a focus on the role of task difficulty in directing selective attention. In Experiment 1, we exposed quail chicks to unimodal auditory, nonredundant audiovisual, or redundant audiovisual presentations of a bobwhite maternal call paired with a pulsing light for 10 min/h on the day following hatching. Chicks were subsequently individually tested 24 h later for their unimodal auditory preference between the familiarized maternal call and the same call with pitch altered by two steps. Chicks from all experimental groups preferred the familiarized maternal call over the altered maternal call. In Experiment 2, we repeated the exposure conditions of Experiment 1, but presented a more difficult task by narrowing the pitch range between the two maternal calls during testing. Chicks in the unimodal auditory and nonredundant audiovisual conditions preferred the familiarized call, whereas chicks in the redundant audiovisual exposure group showed no detection of the pitch change. Our results indicate that early discrimination of pitch change is disrupted by intersensory redundancy under difficult but not easy task conditions. These findings, along with findings from human infants, highlight the role of task difficulty in shifting attentional selectivity and underscore the dynamic nature of neonatal attentional salience hierarchies.

## KEYWORDS

infant selective attention, intersensory redundancy, perceptual development, task difficulty, unimodal facilitation

## 1 | INTRODUCTION

The importance of selective attention in early development cannot be underestimated, as it guides and constrains what can be perceived,

and in turn, what can be learned and remembered (Bahrack & Lickliter, 2014; Bremner et al., 2012; Jankowski et al., 2001). We have proposed and provided converging evidence from both nonhuman animal and human infants that *intersensory redundancy* plays a key role

in the allocation of selective attention in young, relatively inexperienced perceivers (see Bahrnick & Lickliter, 2012; Bahrnick et al., 2020). Intersensory redundancy refers to spatially coordinated and temporally synchronous presentation of the same information (e.g., tempo, rhythm, duration, intensity) across two or more senses. Importantly, only information that is not specific to a particular sensory system (amodal information), such as tempo, rhythm, duration, or intensity, can be redundantly specified across the senses.

We have shown that intersensory redundancy can influence human infants' heart rate, EEG patterns, perceptual discrimination, and learning and memory in the months following birth (e.g., Curtindale et al., 2019; Lickliter & Bahrnick, 2004; Reynolds et al., 2014). Taken together, our findings support what we have termed the intersensory redundancy hypothesis (IRH), a set of related principles that describe how infants' selective attention is allocated to different stimulus properties of objects and events as a function of the type of exploration (unimodal vs. multimodal) afforded by the object or event (Bahrnick & Lickliter, 2000, 2014). In support of this proposal, research findings have consistently indicated that different properties of stimuli are highlighted and attended to when redundant multimodal stimulation is made available as compared with nonredundant unimodal stimulation from the same events during infancy (see Bahrnick & Lickliter, 2012; Bahrnick et al., 2020). For example, during the multimodal exploration of events using more than one sensory system (such as the sights and sounds of a bouncing ball), amodal properties such as synchrony, rhythm, and tempo are more salient and are processed first (*intersensory facilitation*). In contrast, during unimodal exploration of an event (such as talking on the phone or viewing a silent face), modality-specific properties such as shape, color, and pitch are more salient and processed first (*unimodal facilitation*). Our research findings demonstrate that the nature of exploration (multimodal or unimodal) and the stimulation provided (multimodal or unimodal) can significantly influence the properties of objects or events (amodal or modality specific) that are most salient and attract infants' selective attention and perceptual processing.

The role task difficulty plays in affecting perception and allocation of attention across early development has received relatively little research focus (but see Berger et al., 2018; Harnick, 1978). In general, we know that what is difficult in early development often becomes relatively easy in later development. This dynamic nature of task difficulty in relation to the skills of the perceiver creates changing salience hierarchies across development. For example, when perceivers are young, attentional resources are limited and infants may only perceive the most salient properties of stimulation (amodal properties in multimodal stimulation, modality-specific properties in unimodal stimulation). As young infants develop and become more experienced perceivers, their allocation of selective attention during bouts of exploration becomes more efficient and flexible and they are able to detect both amodal and modality-specific properties in unimodal and multimodal stimulation (see Bahrnick & Lickliter, 2004). For example, Bahrnick et al. (2013) found that 2-month-old human infants can show face discrimination when different faces are presented unimodally, but not when presented with bimodal intersensory redundancy (faces of people speaking). By 3 months of age, however, infants were able to

discriminate faces under both unimodal and multimodal conditions. In addition to age and experience, task difficulty can have a profound effect on the allocation of infants' selective attention. For example, when presented with an audiovisual event, 5-month-old infants did not require intersensory redundancy to discriminate amodal tempo changes of low difficulty but did require intersensory redundancy to discriminate amodal tempo changes of moderate and high difficulty. In other words, by increasing task difficulty (and requiring finer tempo discrimination) we were able to reinstate the intersensory facilitation seen earlier in infant development (Bahrnick et al., 2010).

In a prior study of bobwhite quail (*Colinus virginianus*) embryos, we showed that quail *prenatally* exposed to a maternal call were only able to detect a pitch change in that call in subsequent postnatal testing when they had been exposed to unimodal auditory or nonredundant (asynchronous) audiovisual presentations of the call prior to hatching. In contrast, embryos exposed to redundant audiovisual presentations (a light synchronized with the call) did not detect the pitch change in subsequent postnatal tests (Lickliter et al., 2017). Intersensory redundancy between the light and the call interfered with detection of pitch because it directed attention to salient redundantly specified amodal properties at the expense of modality-specific pitch information.

In the current study, we provided the same experimental stimulus presentations and tests as this original prenatal study. However, in the current study quail chicks were exposed to the bobwhite maternal call *postnatally*, after having had more perceptual experience. We reasoned that if chicks' perceptual abilities, processing efficiency, and flexibility of selective attention have increased sufficiently over early development to effectively reduce the overall difficulty of the pitch discrimination task, then chicks should be able to detect a pitch change following unimodal and redundant bimodal preexposure. Our first experiment tested this hypothesis by *postnatally* exposing bobwhite quail chicks to an individual bobwhite maternal call either redundantly (synchronous audiovisual stimulation) or nonredundantly (unimodal auditory or asynchronous audiovisual stimulation) over the course of the day following hatching. Twenty-four hours after the completion of these exposure sessions, chicks were tested individually between the familiar version of the maternal call that was presented previously (i.e., no acoustic changes) versus the same maternal call with an altered pitch range (all other acoustic features held constant).

In a second experiment, we hypothesized that if the task difficulty is increased (relative to the experience of the young chick), then the unimodal facilitation we observed in the prior prenatal study (Lickliter et al., 2017) should again become apparent during chicks' postnatal development. We reasoned that by narrowing the pitch range between the familiarized maternal call and the novel pitch-modified call, chicks' attentional resources would be more taxed and unimodal facilitation to modality-specific properties of the call would again be observed. This prediction follows the logic that if chicks receiving redundant, bimodal stimulation have their selective attention focused on the amodal stimulus properties of the maternal call during the exposure sessions (i.e., rhythm, tempo, or duration), then they would not detect the more difficult pitch change during subsequent testing. In contrast, unimodal auditory and asynchronous audiovisual exposure sessions

would facilitate chicks' attention to the modality-specific property of pitch, because there would be no intersensory redundancy competing for their selection attention in either of these exposure conditions. We tested this latter prediction by narrowing the range of the pitch difference between the familiar version of the maternal call presented previously and the same call with the altered pitch range (all other acoustic features held constant) during testing.

## 2 | GENERAL METHOD

### 2.1 | Subjects

Subjects were 227 incubator-reared bobwhite quail hatchlings (*Colinus virginianus*), incubated and hatched in our lab. Bobwhite quail are a precocial avian species and thus have functioning auditory and visual systems even prior to hatching. Further, their development progresses at a rapid rate compared to mammals, particularly humans. This rapid developmental trajectory and their perceptual capabilities before and after hatching contributes to their usefulness as an animal model for research on early perceptual development.

The protocol and all procedures of this study were approved by our Institutional Animal Care and Use Committee, and we complied with the U.S. Public Health Service's Policy on Humane Care and Use of Laboratory Animals and the Guide for the Care and Use of Laboratory Animals. Fertilized unincubated eggs were received weekly from a commercial supplier and set in an incubator maintained at 75%–80% relative humidity and 37.5°C. Embryonic age was calculated on the basis of the first day of incubation as Day 0, and so forth. To control for possible variations in developmental age, only those birds that hatched on Day 23 were used as subjects. Following hatching, groups of 10–12 chicks were housed in a rearing tub until testing. Chicks were given free access to food and water, except during testing sessions. Ambient air temperature was maintained at approximately 30°C both in the rearing and testing rooms.

### 2.2 | Apparatus

Approximately 24 h after hatching, chicks were transferred to a sound-attenuated stimulation room, maintained at approximately 30°C, and placed in groups of 10–12 in a tub with food and water continuously available. Auditory and audiovisual presentations were delivered by means of a computer with a custom-designed software program running a speaker that broadcasted the bobwhite maternal call. The speaker was placed on an exterior side of the rearing tub. In the audiovisual conditions, the computer software program also ran an amplifier connected to an adjustable lamp that transmitted a pulsed light with the notes of the maternal call. The lamp was placed directly above the tub and easily visible to the chicks. In the synchronized condition, the light provided the same amodal information (onset, rhythm, rate, and duration) as the five notes of the maternal call. It is important to note that chicks in this experiment received their postnatal exposure to the

maternal call or the maternal call paired with the light starting at 24 h of age, approximately 48 h later in development than the prenatal exposure utilized in our original study of pitch discrimination (Lickliter et al., 2017).

Behavioral testing was conducted at approximately 72 h following hatching. Testing occurred in an arena 130 cm in diameter, encircled by a wall 60 cm in height. The arena surface was painted white, and an opaque white curtain covered the wall of the arena. A video camera mounted directly above the arena allowed for remote observation and data collection. Two semicircular approach areas each comprising approximately 5% of the total area of the testing arena were demarcated on a remote video monitor used for data collection. Both approach areas contain a speaker mounted to the arena wall and hidden behind the white curtain to allow for the presentation of auditory stimuli during the testing trials. All chicks were tested individually.

### 2.3 | Procedure

Bobwhite quail chicks were divided into three experimental conditions: (1) a unimodal auditory group was exposed to an individual variant of the bobwhite maternal assembly call for 10 min/h for 24 h starting at approximately 24 h following hatching, (2) a redundant audiovisual group was exposed to an individual variant of the bobwhite maternal call paired with a pulsing light temporally synchronized with the notes of the call for 10 min/h for 24 h, and (3) an asynchronous audiovisual group was exposed to the same maternal call concurrently with the pulsing light presented out of synchrony with the notes of the call (offset by 300 ms) for 10 min/h for 24 h, thereby providing the same amount of audiovisual stimulation (240 min total) as the redundant bimodal group, but with no intersensory redundancy across the auditory and visual stimulation. According to the IRH, intersensory facilitation is due to redundancy across senses and not simply due to the greater overall amount of stimulation in two modalities compared to one modality alone. Consistent with this view, studies of human and nonhuman animal infants have found that intersensory facilitation is not observed under conditions of multimodal stimulation without redundancy (asynchronous but equivalent visual and auditory stimulation, e.g., Bahrack & Lickliter, 2000; Flom & Bahrack, 2007; Lickliter et al., 2002).

Testing was conducted 24 h following completion of the exposure sessions (when chicks were 72 h of age) and consisted of a 5-min (300 s) simultaneous choice test. As in our original prenatal study, all chicks were tested individually between the familiar version of the maternal call that was presented during the exposure session versus the same maternal call altered to a two-step higher or two-step lower pitch range (all other acoustic features held constant). Pitch of the maternal call was altered by the use of computer multimedia software, MAGIX Audio Studio 10 Deluxe. Hence, chicks from all exposure conditions were individually given a simultaneous choice test between acoustically identical recorded bobwhite maternal calls, with the exception that one call retained its familiarized pitch and the other call had a novel pitch.

## 2.4 | Data analyses

As was the case in our original prenatal study (Lickliter et al., 2017), the data of interest for analyses were measures of duration (in seconds) of proximity to the two auditory stimuli presented during testing. A proportion of total duration time (PTDT) was calculated from the time a chick spent in the approach area containing the familiar version of the maternal call relative to the total duration spent in both familiar and modified approach areas. A proportion of .50 represents chance responding. In contrast, a proportion greater than .50 reflects a majority of time spent in the approach area containing the familiar version of the maternal call, whereas a proportion less than .50 represents a majority of time spent in the approach area containing the modified call. One-sample *t*-tests were used to evaluate whether the PTDT spent in the modified call approach area was significantly greater than chance. Nonparametric analyses were also conducted on the raw duration of time (in seconds) spent in each approach area by chicks in a group using the Wilcoxon signed-ranks test.

## 3 | EXPERIMENT 1

A prior study demonstrated that unimodal presentations of an individual maternal call provided *prenatally* facilitated learning of the modality-specific property of pitch (Lickliter et al., 2017). These results are in line with the IRH prediction that in early development (when perceivers are relatively inexperienced) modality-specific properties of objects or events will be most readily detected under unimodal conditions, where redundancy is not available and would not direct infants' selective attention away from modality-specific properties and toward the amodal properties of those objects or events.

The current experiment investigated the developmental course of this prediction in light of these previous findings. The same experimental procedure and pitch ranges (i.e., two-step lower and higher pitch ranges from the original maternal call) were used for the current experiment as were used in the original prenatal study (Lickliter et al., 2017). However, in this case, bobwhite quail were exposed *postnatally* to the maternal call and tested at a later developmental age between the familiarized version of the maternal call versus the same call with altered pitch. We hypothesized that older chicks, having more experienced perceptual systems, would find the discrimination task relatively easier than it had been in prenatal development, and thus would detect pitch changes under both nonredundant auditory (unimodal) and redundant audiovisual stimulus exposure. A third exposure group received nonredundant (asynchronous) audiovisual presentations of the maternal call to control for the overall amount of stimulation presented during the exposure sessions. We expected this group to also show discrimination for the altered pitch.

### 3.1 | Method

One hundred and sixteen bobwhite quail chicks, divided into three experimental conditions (unimodal, redundant bimodal, and asyn-

**TABLE 1** Means and standard deviations of duration scores (in seconds) for Experiment 1

Stimulus condition	N	Familiar call	Pitch-modified call
Unimodal auditory	41	97.81* (71.46)	31.00 (46.47)
Nonredundant audiovisual	40	69.65* (54.81)	34.99 (29.47)
Redundant audiovisual	35	89.69* (56.71)	26.78 (27.42)

\* $p < .05$  (Wilcoxon test).

**TABLE 2** Mean proportion of total duration time and standard deviations (in seconds) for the familiar call for Experiment 1

Stimulus condition	Mean PTDT	SD
Unimodal auditory	.7527*	.269
Nonredundant audiovisual	.6259*	.272
Redundant audiovisual	.7476*	.232

Abbreviation: PTDT, proportion of total duration time.

\* $p < .05$  (*t*-test).

chronous bimodal), served as subjects. All chicks were exposed to an individual maternal call for 10 min each hour for a 24-h period in groups of 10–12 chicks, starting at approximately 24 h following hatching. The unimodal group ( $N = 41$ ) received only auditory stimulation, the redundant bimodal group ( $N = 35$ ) were exposed to the same maternal call that was synchronously paired with a pulsing light (providing intersensory redundancy), and the nonredundant bimodal group ( $N = 40$ ) received the same call concurrently with the pulsing light, but presented 300 ms out of synchrony with the notes of the call (no redundancy). All groups were tested 24 h after the completion of the exposure period (at 72 h of age) in a simultaneous choice test between two variants of the maternal call. At testing, in each condition 50% of subjects received the familiarized maternal call and a maternal call altered to a two-step higher pitch, and 50% of subjects received the familiarized call and a maternal call altered to a two-step lower pitch. It is important to note that control chicks not exposed to any supplemental auditory stimulation do not prefer either modified variant of the maternal call during a simultaneous choice test (Lickliter et al., 2017).

### 3.2 | Results and discussion

Results are shown in Tables 1 and 2. Wilcoxon signed-ranks test revealed that the unimodal preexposure group showed significantly longer duration scores ( $z = -4.024$ ,  $p = .001$ ) for the familiar call than the pitch-modified maternal call. Chicks in the redundant bimodal group also showed significantly longer duration scores ( $z = -4.259$ ,  $p = .001$ ) for the familiar call, as did chicks in the nonredundant bimodal group ( $z = -2.863$ ,  $p = .004$ ).

One-sample *t*-tests were performed on the PTDT spent in the approach area with the familiarized version of the call against the chance value of .50 for all experimental groups. Results revealed that chicks exposed to unimodal presentations of the maternal call

showed a greater PTD to the familiarized version of the call at testing ( $t(40) = 6.007, p = .001$ ). Similarly, chicks exposed to redundant bimodal presentations of the call during preexposure showed a greater PTD to the familiar version of the call at testing ( $t(34) = 6.328, p = .001$ ), as did chicks in the nonredundant bimodal group ( $t(39) = 2.924, p = .006$ ). Mean PTD scores for each condition are shown in Table 2. In sum, both nonparametric and parametric tests indicated that chicks from all three experimental groups preferred the familiarized maternal call over the same call with altered pitch.

These findings support the idea that as chicks develop and gain perceptual experience, their perceptual capabilities increase. Chicks *prenatally* exposed to a bobwhite maternal call were able to detect a pitch change in subsequent postnatal testing only when they were provided with prenatal unimodal exposure (Lickliter et al., 2017). In contrast, in the current experiment using the same stimuli and exposure condition, chicks *postnatally* exposed to a maternal call were able to detect this same pitch change after having received unimodal, nonredundant bimodal, or redundant bimodal exposure prior to testing. Chicks' ability to detect this pitch change across all conditions suggests that the discrimination task had become easier relative to their perceptual capabilities. In this light, we next explored if a more difficult discrimination task was presented during testing, would unimodal facilitation for modality-specific properties (i.e., pitch) seen in our original prenatal study become evident again later in chicks' development? In other words, would the increased task difficulty change the salience of different properties of stimulation such that intersensory redundancy would now interfere with pitch discrimination?

## 4 | EXPERIMENT 2

As attentional systems and perceptual processing improve across early development, attentional flexibility typically becomes more apparent. According to the predictions of the IRH, if tasks are made difficult enough to challenge young perceivers, then the salience hierarchy resulting in unimodal facilitation for modality-specific stimulus properties and intersensory facilitation for amodal stimulus properties should again become evident (Bahrick et al., 2010). In the current experiment, we assessed whether unimodal facilitation for pitch would be evident under conditions of higher task difficulty. The same experimental design of Experiment 1 (i.e., postnatal exposure and subsequent testing) was used; however, the simultaneous auditory choice test was made more difficult by narrowing the pitch range used between the familiarized version of the maternal call and the pitch-modified maternal call.

### 4.1 | Method

A total of 111 bobwhite quail chicks, divided into three experimental conditions (unimodal, redundant bimodal, and nonredundant bimodal), served as subjects. All chicks were exposed in groups of 10–12 to an individual maternal call at 24 h following hatching and subsequently

**TABLE 3** Means and standard deviations of duration scores (in seconds) for Experiment 2

Stimulus condition	N	Familiar call	Pitch-modified call
Unimodal auditory	39	72.46* (52.90)	40.33 (48.92)
Nonredundant audiovisual	37	70.82* (49.43)	35.75 (24.75)
Redundant audiovisual	35	57.05 (50.50)	53.97 (59.28)

\* $p < .05$  (Wilcoxon test).

**TABLE 4** Mean proportion of total duration time and standard deviations (in seconds) for the familiar call for Experiment 2

Stimulus condition	Mean PTD	SD
Unimodal auditory	.6433*	.270
Nonredundant audiovisual	.6235*	.253
Redundant audiovisual	.5335	.291

Abbreviation: PTD, proportion of total duration time.

\* $p < .05$  (t-test).

tested 24 h later between two variants of the call as in Experiment 1. However, in the current experiment the range between the pitch of the unmodified maternal call presented during exposure and the pitch of the modified call with which they were subsequently tested was narrowed, thereby increasing the difficulty of the discrimination task. Specifically, following initial exposure sessions, chicks were tested between the familiar variant of the bobwhite maternal call and the same maternal call with either a one-step higher pitch or a one-step lower pitch. During testing, 50% of subjects received exposure to the unmodified maternal call and the same maternal call altered to a one-step higher pitch and 50% to the familiarized call and the maternal call altered to a one-step lower pitch. The unimodal group ( $N = 39$ ) received only auditory stimulation, the redundant bimodal ( $N = 35$ ) received temporally synchronized audiovisual stimulation, and the nonredundant bimodal group ( $N = 37$ ) received asynchronous audiovisual stimulation during the exposure sessions. All groups were tested approximately 24 h after the completion of their exposure sessions at 72 h of age in a simultaneous auditory choice test between the familiarized and modified variants of the bobwhite maternal call (a one-step range, compared to the two-step range used in Experiment 1).

### 4.2 | Results and discussion

Results are shown in Tables 3 and 4. Wilcoxon signed-ranks test revealed that the unimodal group showed significantly longer duration scores ( $z = -2.986, p = .003$ ) for the familiarized maternal call than the pitch-modified call. Chicks in the nonredundant bimodal group also showed significantly longer duration scores ( $z = -2.950, p = .003$ ) to the familiarized call. In contrast, chicks in the redundant bimodal group showed no significant difference in their duration scores ( $z = -.950, p = .342$ ) for the two variants of the call during testing.

One-sample *t*-tests were also performed on the PTDT spent in the approach area with the familiarized version of the call against the chance value of .50 for all experimental groups. Results revealed that chicks exposed to unimodal presentations of a maternal call showed a greater PTDT to the familiarized version of the call at testing ( $t(38) = 3.316, p = .002$ ), as did chicks in the nonredundant bimodal group ( $t(36) = 2.968, p = .005$ ). In contrast, chicks exposed to redundant bimodal exposure to the maternal call did not show greater PTDT to the familiarized version of the call at testing ( $t(34) = .683, p = .499$ ). Mean PTDT scores for each condition are shown in Table 4.

In sum, individual group analyses using both parametric and non-parametric statistical tests converged and indicated that chicks receiving nonredundant unimodal (auditory only) and nonredundant asynchronous bimodal (audiovisual) postnatal exposure to the maternal call preferred that call over the same call with altered pitch in subsequent testing. In contrast, chicks receiving redundant bimodal (audiovisual) exposure did not prefer that familiarized call over the same call with altered pitch. In other words, when the pitch range was narrowed and the detection of the pitch change became more difficult, unimodal facilitation was observed, as was the case in our original prenatal study (Lickliter et al., 2017) with younger, less experienced quail.

## 5 | GENERAL DISCUSSION

The IRH predicts that the effects of redundancy across senses on selective attention should be most apparent early in development when infants are first learning a skill and detection of amodal and modality-specific properties of objects and events is relatively difficult. Once the skill is mastered and/or perceptual discrimination becomes easier with experience, the information in question (e.g., a particular rhythmic sequence or a particular pitch change) should be detected more efficiently and discriminated in both redundant bimodal as well as unimodal stimulation (Bahrack & Lickliter, 2004, 2014). In other words, the effects of intersensory redundancy should be most apparent when young infants are first learning to differentiate novel or relatively unfamiliar information.

The current study, along with our previous prenatal study (Lickliter et al., 2017), provides further evidence in support of this view. In the previous prenatal study, we found that quail chicks were able to detect a change in pitch (a modality-specific property) of a maternal call following *prenatal* unimodal or nonredundant audiovisual exposure, but not following *prenatal* redundant audiovisual exposure (Lickliter et al., 2017), demonstrating unimodal facilitation of pitch detection. Later in development, chicks were able to detect a change in pitch of a maternal call after *postnatal* exposure to unimodal, nonredundant, or redundant audiovisual stimulation (Experiment 1), no longer showing evidence of unimodal facilitation. However, when detection of the pitch change was made more difficult, chicks once again demonstrated unimodal facilitation, detecting the change in pitch but only following postnatal unimodal or nonredundant audiovisual exposure and not redundant bimodal exposure (Experiment 2), paralleling the results of our previous prenatal study. These results indicate that older chicks revert to patterns of performance seen in younger chicks when task

difficulty is increased. Similar findings on the effects of task difficulty and experience have been reported in studies of human infants presented with perceptual, cognitive, and motor tasks (e.g., Adolph, 2002; Berger, 2004; Corbetta & Bojczyk, 2002).

Taken together, our findings suggest a shift in perceptual learning capabilities from late prenatal to early postnatal development in bobwhite quail. This finding provides new information about how detection of specific stimulus properties can change as a function of perceptual salience as young chicks gain perceptual experience. It has long been known that attentional and perceptual abilities improve and become more flexible across early development (e.g., Bahrack, 1992; Lewkowicz, 2000; Ruff & Rothbart, 1996; Shady & Colombo, 2004). Our present results reveal how this improvement with experience impacts salience hierarchies with respect to selective attention toward amodal, redundantly specified versus modality-specific nonredundantly specified properties. Selective attention toward specific stimulus properties of events in the period following hatching can shift depending on task difficulty. Specifically, as a discrimination task becomes more difficult for young chicks, modality-specific properties are better detected in unimodal stimulation and attenuated in redundant multimodal stimulation, where amodal properties compete for chicks' limited attention.

These findings with quail chicks parallel those that we have obtained with human infants. We found that 2-month-old infants can discriminate a novel face in unimodal visual and nonredundant (asynchronous) audiovisual speech, but not in redundant audiovisual speech. In contrast, by 3 months of age face discrimination was observed even during redundant audiovisual speech (Bahrack et al., 2013). These results indicate that in very early development, intersensory redundancy generated by a face paired with synchronous speech can interfere with discrimination of the modality-specific (visual) features of a face. However, when no intersensory redundancy is made available, infants' selective attention is able to focus on the visual information supporting face discrimination. One month later, older and more experienced infants were able to discriminate faces even in the context of intersensory redundancy, showing visual recovery to a novel face under both unimodal visual and synchronous audiovisual speech conditions.

More generally, our results from both nonhuman and human infants provide support for the dual role (both facilitating and interfering effects) of the salience of intersensory redundancy for attention and perceptual processing of event properties (see Bahrack & Lickliter, 2014 for further discussion). Specifically, multimodal and unimodal stimulations have opposing effects; multimodal events facilitate the detection of amodal properties at the expense of modality-specific properties, whereas unimodal events facilitate detection of modality-specific properties at the expense of amodal properties. Because competition for limited attentional and processing resources likely underlies these opposing effects, they are most evident in early development when young infants are relatively naïve and expertise is low in relation to task demands.

Our results also point to the importance of taking into account the effects of task difficulty on selective attention and perception of different properties of stimulation during early development. Of course, other variables can affect infant discrimination performance,

including complexity of the stimuli and amount of experience with the task presented and these deserve further research. It is clear that selective attention and perceptual processing provide a foundation for what is learned and remembered and our current findings highlight the need for a better understanding of the underlying developmental dynamics of these aspects of early perceptual development.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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