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A Developmental Trajectory of Latent Inhibition

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Latent inhibition is said to occur when learning about the relationship between a cue and an outcome proceeds more readily when the cue is novel relative to when the cue has been rendered familiar through mere preexposure. Previous studies suggest that latent inhibition, while evident in 4- to 5-year-old children, is attenuated or even absent in older children. There are, however, acknowledged shortcomings associated with previous demonstrations of this effect, which we attempted to overcome using a letter prediction task that has been employed in recent studies of latent inhibition in adults. One hundred and seventy-five 4- to 14-year-old children and 175 young adults completed a letter prediction task, with a latent inhibition manipulation embedded within it. Using developmental trajectory analysis we found, contrary to other studies, an increase in the magnitude of latent inhibition as children age, with the effect becoming significant when children were around 6.7 years of age. Model comparison revealed that a linear function best described the relationship between latent inhibition and age. We discuss these findings in the context of theories of learning and attention, and consider the role of concurrent task type as a factor that determines the developmental trajectory of latent inhibition.

Keywords: latent inhibition, development, associative learning, attention, developmental trajectory

Despite its apparent simplicity, latent inhibition has attracted a great deal of theoretical and empirical attention. First reported by Lubow and Moore (1959) in a study of conditioned leg flexion in goats and sheep, latent inhibition is said to occur when learning about the relationship between a cue and an outcome is more rapidly acquired when the cue is novel compared to when the cue has been rendered familiar by mere preexposure. In Lubow and Moore's study, for example, animals received trials in which the illumination of a light and the movement of a rotor blade were presented separately and each paired with the delivery of a mild shock to the foreleg. One of these two stimuli was entirely novel to the animals at the outset of conditioning, whereas the other stimulus had been preexposed 10 times without reinforcement. The results revealed that the acquisition of conditioned leg flexion proceeded more rapidly in the animals when the stimulus was novel compared to when it had been preexposed. The theoretical analysis of latent inhibition falls, broadly, into two camps. On the one hand, there are theories that emphasize the interaction of learning and attention (e.g., Le Pelley, 2004; Lubow, 1989; Pearce & Hall, 1980), with the effect of preexposure said to reduce the attention that is paid to an inconsequential stimulus, thus permitting learning resources to be diverted away from it. On the other hand, interference accounts of latent inhibition propose that preexposure interferes with the acquisition or retrieval of the learning between the cue and the outcome (e.g., Bouton, 1993; Miller & Matzel, 1988). Latent inhibition has been demonstrated in a variety of species; as already noted, it has been observed in goats and sheep (Lubow & Moore, 1959), but it has also been demonstrated in rats (Kaye & Pearce, 1987), in pigeons (Tranberg & Rilling, 1978), honeybees (Abramson & Bitterman, 1986), and even snails (Loy et al., 2006). While latent inhibition can also be found in humans (e.g., Dawes et al., 2022; Evans et al., 2007; Granger et al., 2016), there has been sustained debate about the extent to which the effect is demonstrable without embedding the exposure within other so-called "masking" tasks (for a review, see Byrom et al., 2018). In addition, there is some suggestion that latent inhibition has a peculiar developmental trajectory, in that it is seemingly evident in younger children, but not older children.

In their Experiment 1, Kaniel and Lubow (1986) recruited 240 children and split them into age groups of 4- to 5-year-olds, 5- to 6-year-olds, 6- to 7-year-olds, and 11- to 12-year-olds. During the preexposure stage, the children were presented with a pair of pictures (animals and plants) on the left- and right-hand sides of the experimental apparatus and were rewarded for pressing a button below the pictures of the plants, but not for pressing a button below the pictures of the animals. Crucially, in-between these pictures was a center space for a third picture which constituted the preexposed stimulus (colored squares). During the subsequent test stage, the squares were now presented on the left and right sides of the apparatus, and children were rewarded for pressing the button below one of the pairs of squares, which for some children would be familiar,

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and for others would be novel. The dependent variable in the test phase was the number of trials required to reach a criterion of 10 consecutive correct responses. Interestingly, children in the two youngest groups reached this criterion sooner if the squares were novel at test than if they had been preexposed—that is, latent inhibition was observed. However, children in the two older groups did not show an effect of preexposure, for these children, the criterion was reached after an equivalent number of trials irrespective of whether the squares were novel or preexposed. This pattern of results was reproduced in Kaniel and Lubow's Experiment 2. There are, however, some features of these studies which deserve comment. First, as the authors note, the absence of any difference between the preexposed and novel groups for children above the age of 6 could be due to a ceiling effect. Irrespective of preexposure condition, the task was straightforward for these children, and consequently the mean number of trials required before these children reached 10 consecutive correct trials was around 15 trials. A measure of support for this "ceiling-effect" analysis comes from the fact that when the very oldest group of children was omitted from the statistical analysis, the crucial Age-Group × Preexposure interaction failed to reach significance. Second, although the Age-Group × Preexposure interaction is reported as significant, $F(8, 285) = 1.96$, $p < .05$, by Kaniel and Lubow in their Experiment 2 (Kaniel & Lubow, 1986, p. 371), the critical value of F for these degrees of freedom is 1.97, and so, even without any groups omitted, the second experiment, in fact, fails to reach conventional levels of statistical significance. In order to determine whether the two experiments, together, provide evidence for the crucial interaction, the p value for the Age-Group × Preexposure interaction from Experiment 2 ($p = .051$) was combined with the p value for the Age-Group × Preexposure interaction from Experiment 1 ($p = .048$) as a meta-analysis using Fisher's combined probability test. This analysis reveals a significant result, $\chi^2(4) = 12.03$, $p = .017$.

McLaren et al. (2021) raise another issue with the studies reported by Kaniel and Lubow (1986). They note that the masking task employed may have resulted in inattention/learned irrelevance being conditioned to the preexposed stimuli as these stimuli were explicitly irrelevant to the animal/flower discrimination employed during the preexposure phase of the experiment. To overcome this issue McLaren et al. required children, aged between 4- and 11 years old to press one key when they saw a picture of an animal, and a different key when they saw a picture of a dinosaur during a preexposure phase. Immediately prior to the presentation of these stimuli was the presentation of abstract patterns, which the children were told served as a "warning signal" for the imminent arrival of an animal or a dinosaur, but which provided no information about the identity of the subsequent animal or dinosaur. These abstract patterns were the preexposed stimuli. During the subsequent test phase, the children had to learn to press the space bar during trials with two of the abstract patterns (go trials) but not during the other two trials (no-go trials). One of the patterns on each of the go and no-go trials was preexposed, the other was novel. The results revealed that, in children between the ages of 4 and 5, the mean response accuracy was higher to the novel stimuli than the preexposed stimuli. However, there was no difference in response accuracy between these stimuli in children aged between 6- and 9-years-old, 10 and 11-years-old, or indeed in a group of 18- to 21-year-old undergraduates. These results, then, seem to reproduce the effect that was reported by Kaniel and Lubow; that is, the presence of latent inhibition in children aged between 4 and 5, but not in children older than this. Unlike Kaniel and Lubow's, studies, however, it is difficult to explain the results by appealing to inattention being conditioned to the preexposed stimuli, as they served as signals for an imperative stimulus. Two issues associated with the McLaren et al. study are worthy of further comment, however. Like Kaniel and Lubow, McLaren et al. noted that their task was sensitive to a scaling effect, with older children reaching a performance ceiling by the second half of training in Stage 2. Thus, any apparent loss of latent inhibition in older children could be due to a lack of variation in the dependent variable. To overcome this issue, McLaren et al. analyzed data from only the first half of the test phase. Here, performance in children over 6 years certainly came off the ceiling of performance; however, it is unclear whether a scaling effect remained, with the point on the measuring scale occupied by children aged between 4 and 5 being more sensitive for detecting a difference in responding. A second issue that is worthy of comment is that the Age-Group × Preexposure interaction was only significant for the "go" trials. It failed to reach significance on the no-go trials. Indeed, on no-go trials accuracy was, if anything, higher to the preexposed stimulus compared to the novel stimulus in children aged 4–5. McLaren et al. suggest that this may be a consequence of the preexposed stimulus acquiring a form of general response inhibition during the preexposure stage as children, during this stage, were required to press a button when the animals and dinosaurs were presented, but not press when the abstract patterns were presented.

General response inhibition may also account for the observation of latent inhibition in young children in a study by Lubow et al. (1976). They required children with a mean age of 5 years to learn the objects under which a marble was hidden. Performance (picking up the object) was superior when the object was novel relative to when it was preexposed. However, the instructions given to children during the preexposure asked them:

> When I raise the screen you will see a table and several objects on the table. Please do not touch them. Sit with your hands crossed or by your side, as you like. I want to measure with this watch how long you can sit quietly, watching the table and the things on it, without saying or doing anything.

It is possible that explicitly instructing the children to not touch the stimuli during preexposure led to the acquisition of response inhibition (either general or specific) that hindered subsequent performance, rather than mere exposure to the stimuli. Furthermore, older children were not tested in this experiment, so it is unclear whether the same effect would have been evident across childhood. One other study of latent inhibition, this time in children aged between 10 and 11 years, was reported by Lubow et al. (1982). In their Experiment 4, children in a Pe-M group were preexposed to pairs of circles which contained three scrambled letters and asked to construct a word from the letters. For children in a Group Pre-NM, the "masking" task involving the letters was removed and children were instructed to merely look at the circles; in a NPe group, there was no preexposure to the circles. In a subsequent training stage, the pairs of circles were once again presented, but now the children were instructed that one of the circles in the pair would be correct, and that they were to indicate which one they thought was correct by pointing at it. Corrective feedback was given verbally, and training continued to a criterion of six consecutive correct responses. The results indicated that children who did not receive preexposure (Group NPe) required fewer trials to meet criterion in the training stage than children in the Pe-M group, but not the Pe-NM group. Thus, whether latent inhibition was observed in these 10- to 11-year-olds depended upon the conditions of the preexposure stage: in the absence of a masking task preexposure did not slow later learning—in keeping with the results of the older children tested in Kaniel and Lubow (1986) and McLaren et al. (2021). However, when preexposure was conducted in the context of a concurrent masking task then learning was subsequently attenuated—latent inhibition was observed in older children. It remains unknown how younger children would have performed in this task, as only 10- to 11-year-olds underwent this procedure. Correspondingly, then, it is also unknown whether the masking task would have had a similar mediating effect on their behavior.

In summary, there is converging evidence toward the general conclusion that latent inhibition is observable in younger children but not older children. This suggests that as children age they become less able to shift attentional resources away from a preexposed stimulus and/or become less susceptible to the interfering effect of preexposure. This would seem to set latent inhibition apart from the results of many, related, studies of the development of executive control. For example, following a review of the literature, Anderson (2002) concluded that attentional control, cognitive flexibility, goal setting, and information processing all showed improved developmental trajectories between the ages of 4 and 14 (see also De Luca et al., 2003; Katus et al., 2023; Klimkeit et al., 2004; Luciana & Nelson, 2002). However, there are sufficient nuances and shortcomings within the study of the development of latent inhibition to warrant further investigation. In the current study, we employed a task used on several occasions to successfully reveal an effect of stimulus preexposure on later learning in young adults (Dawes et al., 2022; Granger et al., 2016). During the preexposure stage of this task, participants are repeatedly presented with a series of individual letters (D, M, T, or V) which are presented on screen for 1,000 ms and separated by an interstimulus interval of 50 ms. Occasionally, a preexposed stimulus (counterbalanced as H or S) is also presented, and during this stage participants are instructed to verbally report the identity of the letter on screen. During the subsequent test stage, this series of individual letters continues to be presented, but now participants are instructed to make a key press whenever they see a target letter X or, if they think they can predict it, before the presentation of X. This latter response is possible because the presentation of the letter X is preceded by two cues: on some trials the target is preceded by a novel cue, and on other trials it is preceded by the preexposed cue. Using this procedure two things can be observed: (a) a progressive reduction in response times (RTs) to X across the test stage and (b) that this reduction in RTs is more rapid following trials with the novel cue than the preexposed cue—latent inhibition. This procedure has a number of desirable characteristics for studying the emergence of latent inhibition in children. First, as already noted, the difference in responding to the novel and preexposed cue is reliably observed in young adults. Therefore, it is unlikely that the task will be so straightforward for older children that any absence of a difference in responding to the novel and preexposed stimulus is a consequence of a performance scaling effect (cf., Kaniel & Lubow, 1986; McLaren et al., 2021). Second, during the preexposure stage, participants are required to verbalize all the stimuli presented to them, including the preexposed cue. As Granger et al. note, this renders the preexposed cue task relevant. It is therefore difficult to explain slower RTs to the preexposed cue in terms of either learned inattention/irrelevance or general response inhibition (cf., Lubow et al., 1976; McLaren et al., 2021). Finally, unlike early studies of the development of latent inhibition in children, with this procedure the effect of preexposure is investigated within subjects (McLaren et al., 2021), permitting a single measure of latent inhibition to be derived to serve in developmental trajectory analysis.

Kaniel and Lubow (1986, p. 367) state that the main purpose of their studies was "to generate a developmental curve for latent inhibition," and the goal of the current study is the same. Our approach to generating this curve differs, however. Kaniel and Lubow arranged children into groups based on school year (see also McLaren et al., 2021) and then compared the rate of learning to preexposed and novel stimuli within these groups. Here we follow the developmental trajectory approach described by Thomas et al. (2009) in which age is entered into analyses as a continuous variable in order to characterize a function that relates performance to age. To provide some context to our overall latent inhibition result obtained in children we also include a group of young adults tested on the same task. To anticipate our results, and in contrast to previous studies, we observed an increase in the magnitude of latent inhibition as children age, and model comparisons revealed that a linear rule between age and latent inhibition was sufficient to explain this relationship.

Method

Participants

One hundred and seventy-five children (89 female and 78 male), with a mean age of 8.50 years ($SD = 2.32$), were recruited during Summer Scientist Week, an annual public engagement event conducted at the University of Nottingham during 2019, 2021, and 2022 (for more details, see https://www.nottingham.ac.uk/psychology/outreach/summer-scientist-week/about-summer-scientist-week.aspx). All children had normal or corrected-to-normal vision, and participated with parental consent. In return for participation, all children were given a token that allowed them to play a game at the event. The study described here received ethical approval from the Ethics Committee at the School of Psychology, University of Nottingham, United Kingdom or the School of Psychology, University of Nottingham, Malaysia.

McLaren et al. (2021), reported η_p^2 values of between .07 and .08 for interaction effects involving stimulus (i.e., preexposed vs. novel) and age group in their overall analyses. To compute a required sample size for a linear regression with a single coefficient, these two η_p^2 were converted to f^2 (Cohen, 1988, p. 281) according to the formula $f^2 = \eta_p^2/(1-\eta_p^2)$. A power analysis was conducted using G*Power 3.1.9.7 (Faul et al., 2007) to estimate the minimum sample size required. This showed that the required sample size to achieve 95% power for detecting an effect size of $f^2 = 0.09$ or $f^2 = 0.08$ at a significance level of $\alpha = .05$ with one predictor was $N = 154$ or $N = 178$ for a two-tailed regression analysis. Thus, the obtained sample size of $N = 175$ was appropriate.

In addition, an equivalently sized sample of 175 adults (153 female and 22 male), with a mean age of 19.28 years ($SD = 1.66$) was recruited from the University of Nottingham, United Kingdom (113 participants) and Malaysia campuses (62 participants). All participants had normal or corrected-to-normal vision.

Apparatus and Materials

Participants were tested individually using Apple iMac or HP computers (screen width 21.5-in.) or a Dell laptop (screen width 13.5-in.). Psychopy (Peirce et al., 2019) was used to present stimuli to participants, record responses, and control the experimental events. A small table (approximately 60 cm in height) and accompanying chair were used to ensure the computer screen was at the participant's eye height. Participant's responses were recorded using a keyboard. The stimuli were white capital letters in Arial font set to Psychopy's height unit of 0.1, where a letter with a height unit of 1 would equal the entire height of the screen. Stimuli were presented for 1,000 ms each and presented in the center of the screen on a grey background. "S" and "H" served as either the preexposed cue or nonpreexposed cue, counterbalanced across participants. The target (outcome) was the letter "X," and distractor letters were D, M, T, and V.

Design and Procedure

The task had two stages: a preexposure stage and a test stage. At the beginning of the preexposure stage an information screen containing instructions for the task was presented:

> I want you to watch the letters that will appear on the screen. I would like you to say the letters out loud as they appear.
>
> This will take about 3 minutes to do, then we are going to do something else.

Adults simply read these instructions, children were given the option to read the instructions themselves or for it to be read to them. During the preexposure stage, participants were presented with the preexposed stimulus 20 times, intermixed in a random order with presentations of "distractor" letters, each of which was presented 15 times. Each stimulus was presented for 1,000 ms, separated by a 50 ms interstimulus interval. The novel and target stimuli were not presented during the preexposure stage.

At the end of the preexposure stage, a second set of instructions was presented. For the children, these instructions read:

> Now, for this part of the game, I want you to watch the letters on the screen again. But now, don't say anything. Instead, I want you to press the spacebar whenever you think the letter X is going to appear. At first it is OK to just press the spacebar when you see X, but as you keep going, see if you learn when it is going to come on so you can press the spacebar first!
>
> If you understand the rules, you can start now.

For adult participants, the instructions read[1]:

> In this task I want you to watch the sequence of letters appearing on the screen. Your task is to try and predict when a letter "X" is going to appear. If you think you know when the "X" will appear then you can press the space bar early in the sequence, that is before the "X" appears on screen.
>
> Alternatively, if you are unable to do this please press the space bar as quickly as possible when you see the letter "X." There may be more than one rule that predicts the 'X.' Please try to be as accurate as you can, but do not worry about making the occasional error. If you understand your task and are ready to start press the space bar to begin.

During the test stage, there were 20 "trials" during which the preexposed stimulus was followed by the target stimulus (X) and 20 trials when the nonpreexposed stimulus was followed by the target stimulus. RTs on these trials constitute our primary dependent variable. Intermixed with these trials were 64 presentations of each of the distractor letters (D, M, T, and V), presented in a random order, as well as five trials with each of the distractor stimuli followed by the target stimulus (X). Consequently, the contingency between the stimuli of most interest (the preexposed and nonpreexposed stimuli) and the target was relatively high (but not perfect, as there were occasions in which X was presented in their absence), and the contingency between the distractors and the target was very low (as there were many occasions in which the distractors were presented in the absence of the target). In keeping with the preexposure stage, each stimulus was presented for 1,000 ms, separated by a 50 ms interstimulus interval. For trials where the preexposed and nonpreexposed stimuli were followed by X, RTs were recorded as the latency of the first response from the onset of the cue (H or S) to the end of the target. Thus, RTs could vary from 0 (a response made at the very start of H or S) to 2.05 s (a response made at the very end of the target). RTs shorter than 1.05 s indicate responses performed before the onset of the target cue, RTs longer than 1.05 s indicate responses performed during the target (see Figure 1).

Transparency and Openness

In this study, we detail how we determined our sample size, processes for identifying any data to be excluded, any data exclusions, all manipulations, and all measures in the study. Statistical analyses were conducted using JASP 0.17.1, IBM SPSS Statistics 28.0.1.1, and custom Excel worksheets. Power analysis was conducted using G*Power 3.1.9.7, and all experiments were controlled, and data collected using the open-source software, PsychoPy. The design and analysis of experiments were based on previously published manuscripts but were not preregistered. Data and study materials are available upon request to the corresponding author.

Results

Data Treatment

Trials with RTs three standard deviations slower or faster than the overall mean were removed, resulting in a small loss of trials (children = 1.7% of trials, adults = 2.4% of trials). Following this initial screening, any participant who failed to respond to half or more of the trials with either the preexposed or the novel stimulus was omitted from further analysis. This resulted in eight children (four female and four male, $M_{\text{age}} = 5.69$ years, $SD = 2.53$) being removed from the sample, and three adults (two female and one male, $M_{\text{age}} = 22.33$ years, $SD = 1.53$). 13.5% and 5.71% of trials in the children's and adult's samples, respectively, contained missing values. Estimates for these values were calculated with imputation using

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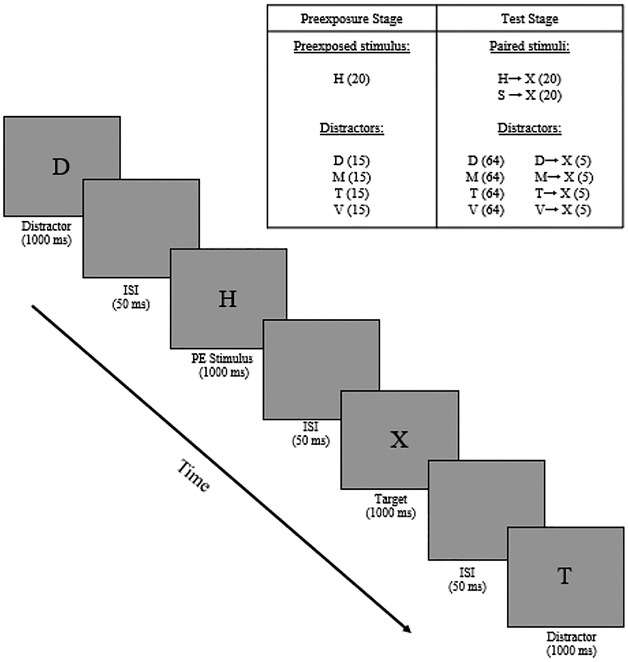
[1] Variations in the instructions provided to adults and children means that there is a confound in the comparison between the data for adults and children. The alternative is to provide the same instructions across children and adults. This approach may lead to differences in the extent to which children/adults regard them as too complex and/or patronising respectively. Which is again a confound.

Figure 1
Design of the Experiment



Note. Overlapping gray boxes show an example timeline of a segment of the test stage in which distractor Stimuli D and T precede and follow the pairing of a preexposed Stimulus H with the target Stimulus X. Inset shows the overall design of the experiment. Numbers in parentheses refer to the number of times each letter, or pair of letters were presented. ISI = interstimulus interval; PE = preexposed stimulus.

the R package, missForest. This method uses a random forest (i.e., multiple decision tree) algorithm on the observed data to predict missing values. It has been shown to outperform other methods of imputation, especially where interactive or nonlinear relationships are suspected. At the same time, it is relatively computationally efficient (e.g.: Stekhoven & Bühlmann, 2012; Waljee et al., 2013).

In all statistical tests, we adopt a significance level of .05. Greenhouse–Geisser corrected degrees of freedom were used where Mauchly's test indicated that the assumption of sphericity was violated, but for ease of exposition, we report degrees of freedom rounded to the nearest integer.

Latent Inhibition—Effects of Age in Children and a Comparison to Adults

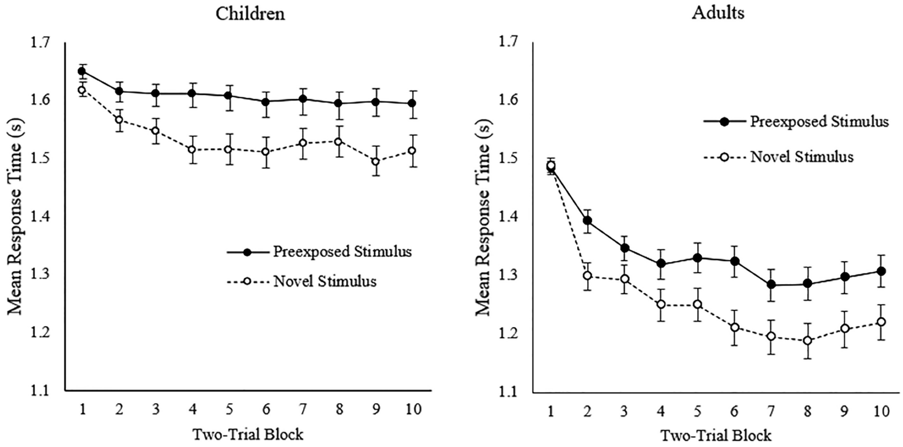
RTs to two successive trials of the same type (e.g., the first and second H–X trials, the third and fourth H–X trials, etc.) were averaged to create two-trial "blocks." The left panel of Figure 2 shows the mean RTs to the preexposed and novel stimulus across the 10 two-trial blocks of the test stage for the children. To provide context to these data we also report data from a young adult sample shown in the right panel. RTs, overall, were slower in children than in adults, but in both groups, a latent inhibition effect was apparent—the rate of responding declined more rapidly to the Novel stimulus compared to the Preexposed stimulus. Indeed numerically, the differences in RT to the preexposed and nonpreexposed stimuli appear comparable in the adults relative to the children. A three-way analysis of variance of individual RTs with the variables of stimulus (preexposed vs. novel), trial block (1–10), and group (adults vs. children) supported this impression revealing a significant main effects of stimulus, $F(1, 337) = 41.62$, $p < .001$, $\eta_p^2 = .12$; trial block, $F(5, 1571) = 40.21$, $p < .001$, $\eta_p^2 = .19$; and group, $F(1, 337) = 120.70$, $p < .001$, $\eta_p^2 = .26$. The Stimulus × Group interaction was not significant, $F(1, 337) = 0.008$, $p = .93$, $\eta_p^2 < .001$, and neither was the three-way Stimulus × Trial Block × Group interaction, $F(8, 2693) = 1.07$, $p = .38$, $\eta_p^2 = .003$. However, the two-way Trial Block × Group interaction was significant, $F(5, 1571) = 10.33$, $p < .001$, $\eta_p^2 = .03$, as was the Stimulus × Trial Block interaction, $F(8, 2693) = 3.70$, $p < .001$, $\eta_p^2 = .01$, indicating an overall latent inhibition effect. Simple main effects analysis of this final interaction (collapsed across the two groups) revealed a significant difference between the preexposed and novel stimulus from trial block 2 onward (Fs > 13.64, all ps $< .001$).

It is useful to compare RTs during the trials with the preexposed and novel stimuli to the trials in which X was presented following the distractor trials (i.e., when they were, essentially, uncued). For both the children and adults, RTs remained constant across the 20 presentations of X when it was preceded by a distractor stimulus, therefore the mean RT was calculated across the test stage for these trials, and compared with the mean RTs on trials with the preexposed and novel stimuli (again averaged across the test stage). These means are shown in Table 1. There was a significant difference between these means for the children, $F(2, 286) = 31.94$, $p < .001$, $\eta_p^2 = .16$. Bonferonni corrected post hoc tests revealed that each mean differed from every other mean, ts > 3.54, ps $< .001$. There was also a significant difference between these means for the adults, $F(2, 317) = 370.32$, $p < .001$, $\eta_p^2 = .29$. Bonferonni corrected post hoc tests again revealed that each mean differed from every other mean, ts > 3.67, ps $< .001$.

To determine if the magnitude of latent inhibition is influenced by age in the group of children, we conducted analysis of covariance (ANCOVA) of RTs, with trial blocks (1–10) and stimulus (preexposed vs. novel) as within-subjects factors, and mean-centered age as a covariate. It is necessary to mean-center the age covariate when performing this analysis, as it has been demonstrated that tests of within-subjects main effects are altered when the mean of a covariate differs from zero (see Delaney & Maxwell, 1981; Thomas et al., 2009). By mean-centering age (subtracting the mean age of the entire sample from individual ages) the mean of the covariate becomes zero but, importantly, this rescaling does not influence tests of the main effect or interactions with the covariate. This analysis revealed a significant main effect of the covariate, $F(1, 165) = 65.67$, $p < .001$, as well as significant main effects of stimulus, $F(1, 165) = 26.19$, $p < .001$, $\eta_p^2 = .14$ (indicating the presence, overall, of latent inhibition), and trial block, $F(6, 997) = 7.76$, $p < .001$, $\eta_p^2 = .045$. The Stimulus × Trial Block interaction was not significant, $F(8, 1308) = 1.66$, $p = .11$. However, both the Stimulus × Mean-Centered Age interaction, $F(1, 165) = 9.66$, $p = .002$, $\eta_p^2 = .06$, and the overall Stimulus × Trial Block × Mean-Centered Age interaction, $F(8, 1308)\ 2.62$, $p = .008$, $\eta_p^2 = .016$ were significant. These interactions imply that the difference in RTs to the novel and preexposed stimuli varies depending on the age of the child. The remaining Trial Block × Mean-Centere Age interaction was also significant, $F(6, 997) = 4.02$, $p < .001$, $\eta_p^2 = .024$. To determine the nature of this relationship between age and latent inhibition, developmental trajectory analysis was performed.

Figure 2

Mean Response Times to the Preexposed and Novel Stimuli Across the 10 Two-Trial Blocks of the Test Stage for Children (Left Panel) and Adults (Right Panel)



Note. Error bars show 1 ± *SE* of the mean.

Developmental Trajectory Analysis

To analyze the training data, mean RTs were first calculated across all 10 two-trial blocks separately for the preexposed stimulus and the novel stimulus for each participant. We then calculated, for each participant, a latent inhibition score which = RT to the Preexposed stimulus divided the sum of the RTs to both stimuli, that is, $RT_{Pre}/(RT_{Pre} + RT_{Nov})$. With this measure, scores greater than 0.5 indicate the presence of shorter RTs to the novel stimulus relative to the preexposed stimulus (i.e., latent inhibition). Scores equal to 0.5 indicate that RTs to the preexposed and novel stimulus were equivalent (i.e., no latent inhibition). To examine whether latent inhibition was related to the age of the children, individual ages were regressed onto latent inhibition scores. Following Thomas et al. (2009; see also Buckley et al., 2015), we rescaled the age predictor to reflect the months from the youngest age (MFYA) tested within our sample. Rescaling ages in the manner does not alter the predictive ability of age, but it does adjust the *y* intercept of the regression model such that it occurs at the youngest age within our sample. This seemed particularly prudent in our sample as children under the age of 4 would be unlikely to have yet learned the letters of the alphabet (i.e., our experimental stimuli) and so generalizing below this age is particularly hazardous.

Age was a reliable predictor of latent inhibition score and accounted for a significant proportion of variance within the data, $R^2 = .073$, $F(1, 165) = 12.93$, $p < .001$. Figure 3 shows that as age increased, RTs to the novel stimulus became faster relative to the preexposed stimulus (i.e., latent inhibition increased, not decreased, as children aged). In order to gain an estimate of the age at which children begin to reliably show latent inhibition we examined the point at which the lower bound of the 95% confidence interval crossed the chance value of 0.5. This approach is similar to the method described by Thomas et al. (2010; see also Thomas et al., 2009) who used the upper and lower bounds of 95% confidence intervals to determine the chronological age at which different developmental trajectories diverge or converge (see also Buckley et al., 2015, 2024). For the current sample and procedure, children above the age of approximately 6.7 years demonstrate latent inhibition (see also Table 2).[2] In addition to linear regression, quadratic, cubic, compound, growth, and exponential functions were also calculated. Only quadratic and cubic regressions generated R^2 values that were greater than the linear regression of .073 (quadratic $R^2 = .075$, cubic $R^2 = .077$). Extra sum-of-squares tests (Motulsky & Christopoulos, 2004) comparing the linear with the quadratic and the linear with the cubic regressions were not significant, $F(1, 164) = 0$, $p = 1$, and $F(2, 163) = 0.39$, $p = .68$, respectively, indicating that the greater number of parameters in the quadratic and cubic models are both more expensive than the greater fits that they provide, and thus the linear model is the better.

Table 1

Mean (and Standard Error) Reaction Times to the Target Stimulus on Trials With the Preexposed Stimulus, Novel Stimulus, and on Trials With Distractor Stimuli) for Adults and Children

Group	Preexposed stimulus	Novel stimulus	Distractor stimuli
Adults	1.337 (0.020)	1.260 (0.022)	1.503 (0.009)
Children	1.609 (0.014)	1.534 (0.020)	1.668 (0.009)

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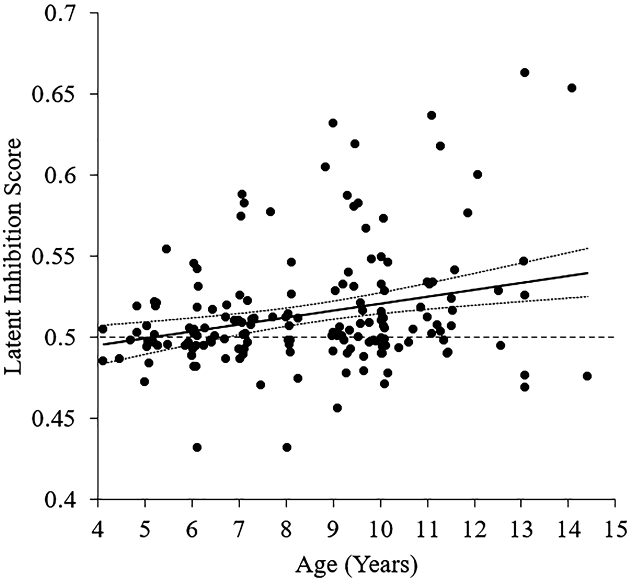
[2] We conducted two further regressions to confirm the validity of the analysis reported in the main text. First, we reproduced the analysis reported in the main text, with a difference score (RT preexposed − RT Novel) as the DV rather than the ratio score. The R^2 value was reduced, but the conclusion was the same: age was a reliable predictor of latent inhibition score, and accounted for a significant proportion of variance within the data, $R^2 = .050$, $F(1, 165) = 9.65$, $p = .002$. The standardized coefficient $\beta = .24$, $t(166) = 3.11$, $p = .002$. Second, an identical regression of latent inhibition ratio scores onto months from youngest age, was calculated from the sample prior to any outliers being removed ($N = 175$), or any imputation conducted. The R^2 value was again reduced, but the conclusion was the same: age was a reliable predictor of latent inhibition score, and accounted for a significant proportion of variance within the data, $R^2 = .055$, $F(1, 173) = 9.99$, $p = .002$. The standardized coefficient $\beta = .23$, $t(174) = 3.16$, $p = .002$.

Figure 3

Individual Latent Inhibition Scores Plotted Against Age



Note. The solid black line represents the linear regression model of age predicting latent inhibition score, dotted lines represent the upper and lower 95% confidence intervals of the model. The dashed horizontal line illustrates the value at which response times to the preexposed and nonpreexposed stimuli are equivalent (0.5).

Scaling Effects

Kaniel and Lubow (1986) and McLaren et al. (2021) all note the presence of scaling effects in their data—performance reached ceiling levels in older children, obscuring any potential effects of age on the tasks. The current data, if anything may encounter the opposite issue, a floor effect, so that performance in younger children is so poor there is no room to see a latent inhibition effect that might otherwise be there. Our first analysis examined whether responding was indeed at the absolute floor of performance in young children who were not demonstrating latent inhibition. To do this we split our sample of children into younger and older groups at the age at which linear regression suggested latent inhibition emerges in our sample, and with the task employed (6.7 years) and compared RTs to the novel and preexposed stimuli to the absolute floor of performance (2.05 s). If the absence of latent inhibition in the younger groups is fully at floor level, then RTs to the preexposed and novel stimuli should be comparable to the longest possible RT during these trials. For the younger group ($N = 43$, oldest child = 6.49 years) RTs were averaged across the 10 two-trial blocks for the preexposed and novel stimuli. The mean (and *SD*) RTs to these stimuli were, respectively, 1.71 s (0.09) and 1.70 s (0.10) which were both significantly faster than 2.05 s, smallest $t(42) = 22.23$, $p < .001$, smallest Cohen's $d = 3.39$.

Although the younger children in our sample were not performing at the absolute floor of performance, it is still the case that our original ANCOVA revealed an overall effect of age on RT (see Figure 3). Therefore, children under the age of around 6.7, who are not demonstrating latent inhibition, might still be performing at a point on the measuring scale that is less sensitive for detecting differences in RT, and that this apparent difference in latent inhibition may be driving the significant linear regression. To investigate this issue, we followed the procedure employed by Kaniel and Lubow (1986) and omitted children below this age and reran a linear regression on the remaining children ($N = 124$, youngest child 6.71 years). The logic here is that if we can still show that the magnitude of latent inhibition increases with age, even in a sample of children who, on average at their youngest age are still showing latent inhibition, then we can be more confident that we are observing a real developmental trajectory. Even under these circumstances, age was still a reliable predictor of latent inhibition score, and accounted for a significant proportion of variance within the data, $R^2 = .034$, $F(1, 122) = 4.27$, $p = .041$. Regression coefficients from this analysis are shown in Table 3. An additional advantage of this particular analysis is that by including only children above the age of the 6.7 years, the variability in the dependent variable is much more consistent across different ages (see Figure 3).

Anticipatory Responding

RTs faster than 1.05 s indicate responses performed before the onset of the target cue (i.e., were anticipatory responses performed during the cues or during the interstimulus interval). The left panel of Figure 1 indicates that, on average, children were relatively reluctant to make anticipatory responses to either the preexposed or novel stimulus. To determine if anticipatory responding was influenced by preexposure, and indeed the age of the child, the mean percentage of responses faster than 1.05 s was calculated for each child separately for the preexposed and nonpreexposed stimuli. For the preexposed stimulus the mean percentage (and standard error) of responses that were anticipatory was 7.43% (1.13) and for the novel stimulus it was 11.40% (1.58). A one-way ANCOVA with the factor of stimulus (preexposed vs. novel) as a within-subjects factors, and mean-centered age as a covariate revealed that the difference between these means was significant, $F(1, 173) = 12.78$, $p < .001$, $\eta_p^2 = .069$, as was the effect of mean-centered age, $F(1, 173) = 21.35$, $p < .001$, $\eta_p^2 = .011$. More importantly, the Stimulus × Mean-Centered Age interaction was significant, $F(1, 173) = 5.38$, $p = .022$, $\eta_p^2 = .03$. A difference score was calculated in which the percentage of anticipatory responses to the preexposed stimulus was subtracted from the

Table 2

Regression Coefficients From an Analysis Where Age (Months From Youngest Child) Was Used to Predict Latent Inhibition Scores

Predicting variable	*B*	*SE B*	95% CI *B*	β	*p*
Constant	0.495	0.006	[0.484, 0.507]		
Age	0.000	0.000	[0.000, 0.001]	.27	<.001

Note. CI = confidence interval.

Table 3

Regression Coefficients From an Analysis Where Age (Months From Youngest Child) Was Used to Predict Latent Inhibition Scores, Using a Subsample of Children (Age > 6.7 Years)

Predicting variable	*B*	*SE B*	95% CI *B*	β	*p*
Constant	0.496	0.011	[0.474, 0.519]		
Age	0.000	0.000	[0.000, 0.001]	.18	.041

Note. CI = confidence interval.

percentage of anticipatory responses to the novel stimulus. Values greater than zero with this measure would indicate the presence of latent inhibition. In keeping with our earlier analyses, linear regression revealed that MFYA was a significant predictor of the difference score, $R^2 = .030$, $F(1, 173) = 5.38$, $p = .022$. The standardized coefficient $\beta = .17$, $t(174) = 2.32$, $p = .022$. Thus as age increased, so too did the magnitude of latent inhibition.

General Discussion

Children between the ages of 4 and 14 received training trials in which a target stimulus was, on some trials, cued by a stimulus that had been rendered familiar during a preexposure stage, and on other trials cued by a stimulus that had not been preexposed. As these training trials progressed, children's RTs on the trials with the novel stimulus reduced more rapidly relative to trials with the preexposed stimulus–latent inhibition. A variety of measures of latent inhibition were calculated for each child that reflected the RTs on trials with the preexposed stimulus relative to responding overall. In all of these measures, regression revealed that children's age accounted for a significant proportion of the variance in this measure. Further analysis revealed a linear increase in the magnitude of latent inhibition as children aged, with the effect reaching significance between the ages of 6 and 7 years.

The results observed in the current experiment contrast with the outcomes of other studies which have investigated the development of latent inhibition during childhood. Both Kaniel and Lubow (1986) and McLaren et al. (2021) observed the presence of latent inhibition in a group of younger (4- to 5-year-olds) but not older children. It is possible that some of the issues that were identified in the introduction are responsible for this discrepancy. For example, differences in the impact of response inhibition and/or ceiling/floor effects that were confounded with age. In their discussion of developmental trajectory analysis, Thomas et al. (2009, p. 340) emphasize that "one of the biggest current challenges is to calibrate measurement systems to afford age-level sensitivity while at the same time retaining conceptual continuity over large spans of time." We are extremely sympathetic with this suggestion. It is hoped that the mitigation that we put in place, in which younger children (who, as a group, did not demonstrate significant latent inhibition) were omitted from a reanalysis has at least partly overcome this issue. Of course, what we cannot say with certainty is that if this younger group of children had been tested in a manner that permitted their demonstration of latent inhibition, then the effect would have been even more substantial in magnitude than that observed in the older children. Thus, we draw a more conservative conclusion—in a sample of children for whom latent inhibition can be detected, the effect increases in magnitude with age.

An early motivation for studying latent inhibition in children was converging evidence from a similar phenomenon called the stimulus familiarization effect (SFE), which refers to the tendency to respond more rapidly to a familiarized stimulus than a nonfamiliarized stimulus. In a review of ten SFE experiments with children, Cantor (1969) described studies employing lever pulling, button pressing, and choice responses. Across these studies, children aged between 5 and 8 years evidenced reliably faster RTs to nonfamiliarized stimuli relative to familiarized stimuli. However, in a study of the rates of galvanic skin responses in adults, Meyers and Joseph (1968) did not observe any differences in responses to familiarized and nonfamiliarized stimuli. Clearly, it is hazardous to make direct comparisons across experiments, especially when such discrepant response systems are involved. However, in two experiments reported by Lubow et al. (1975) children aged, on average, 6.5 years demonstrated that button-press RTs to a visual stimulus slowed as function of the number of times the stimulus was familiarized. The same pattern of results, using the same procedure, however, was not observed in young adults—whose RTs were uniformly faster than children's, with no effect of familiarization. It is tempting to draw parallels between the SFE and latent inhibition, particularly in the context of the current experiment in which RTs constituted the dependent variable. However, studies of the SFE instruct participants to respond to a stimulus, rather than learn the relationship between it and a subsequent outcome, as in the case of latent inhibition. Furthermore, there has been little systematic investigation of the effect of age on this effect. An interesting avenue for future research here would be to establish parameters that permit the observation of the SFE in adults and then explore the effect, with these parameters, across development in children.

In order to explain their observation of latent inhibition in younger, but not older children, Kaniel and Lubow (1986) appealed to conditioned attention theory (Lubow et al., 1981). According to this analysis, repeated presentation of a stimulus results in a decline in attention to that stimulus. However, attention can be acquired to a stimulus whenever it is paired with a subsequent event (see also Esber & Haselgrove, 2011; Mackintosh, 1975). Kaniel and Lubow proposed that in adults, the normal decline in attention to a stimulus during preexposure is attenuated as a consequence of a verbal mediating response being elicited by the preexposed stimulus (e.g., some kind of verbal label that is attached to the stimulus). The effect of this mediating response is to effectively result in pairings of the preexposed stimulus with some kind of subsequent event, and hence allow attention to be acquired to the preexposed stimulus. It is assumed that in children (and animals) this mediating response is less prevalent and consequently latent inhibition can be observed. Putting aside the question of why a nonverbal mediating response could not be elicited in younger children or animals, this analysis of latent inhibition encounters problems when applied to the task used during the preexposure stage of the current study. Here, participants were asked to verbalize the stimuli presented on screen during the preexposure stage and, according to Kaniel and Lubow's analysis, the preexposed stimulus should therefore undergo pairings with another event. Consequently, latent inhibition should not have been observed at all. It is possible, of course, that younger children engaged less with the task of verbalizing the stimuli during preexposure than the older children. However, according to the analysis of latent inhibition developed by Kaniel and Lubow, under these circumstances then we should have seen better latent inhibition in younger children than older children. Of course, the results of the current experiment were contrary to this.

McLaren et al. (2021; see also Graham & McLaren, 1998) discussed how alternative features of preexposure may contribute toward an apparent "latent inhibition" effect above and beyond any influence of mere stimulus preexposure. For example, response inhibition and learned irrelevance were considered, in the introduction, as two potential factors that may have contributed toward poorer performance to a preexposed stimulus relative to a nonpreexposed stimulus. In the current study, during preexposure, participants were required to verbalize all the stimuli presented on screen, including the preexposed stimulus; during the test stage, a button-press response was required during either the target stimulus, or during the stimuli that preceded it. It seems unlikely that being asked to verbalize the stimuli during preexposure led to the acquisition of learned irrelevance (as all the stimuli were task relevant) or response inhibition (as participants were not instructed to refrain from button pressing during preexposure). However, it is possible, that the verbal response acquired to the preexposed stimulus interfered with the acquisition of the button-press response to the same stimulus during the test stage, thus slowing RTs to it. We cannot rule out the contribution of response interference in the current task overall. However, response and indeed stimulus, interference effects have been well studied in the developmental psychology literature. Cragg (2016) notes, for example, that performance in go/no-go, antisaccade, and stop-signal tasks all improve during childhood, suggesting that control over response interference improves with development. We are unaware of any studies that have measured the developmental trajectory of response interference between verbal responses and motor responses such as button pressing. However, if this form of response interference is comparable to other forms of response interference, then its impact might be expected to diminish as children age. This being the case, then, it follows that the difference in performance to the preexposed and nonpreexposed stimuli should diminish too. This is the opposite pattern of results that were observed in the current study. Alternatively, then, perhaps the impact of response interference in our task is one that specifically increases with age. Age is positively correlated with exposure to the alphabet; consequently, the verbal response of letter naming in older children will be much better established than in younger children and may therefore interfere to a greater extent with button-press responding during test.

In light of the discussion above, it is useful to consider whether the nature of the task employed during preexposure is in some way related to the developmental trajectory of learning about preexposed and nonpreexposed stimuli. A taxonomy of latent inhibition procedures has yet to be fully worked out, However, in their review of latent inhibition in humans, Byrom et al. (2018) identified 59 studies, with 52 of these reporting an attenuation in responding to the preexposed stimulus. They note that in the majority of these studies some kind of concurrent, or "masking" task[3] was employed during preexposure to engage participants with the experiment. Byrom et al. (2018) provided a categorization of the different concurrent tasks employed in studies of latent inhibition: (a) where the task uses stimuli that are distinct from the stimuli that will be used in subsequent training; (b) a task which directly involves the stimuli to be presented during training; and (c) a task which has consistent instructions across preexposure and training. The current study included a type (b) concurrent task, as participants were required to name the stimuli (letters) that would later be presented during training. Perhaps, then, the type of concurrent task that children are asked to engage with during preexposure may determine the form of the developmental trajectory of latent inhibition. This possibility was suggested by Kaniel and Lubow (1986) who proposed that latent inhibition was only observable in older children "under special masking conditions" (p. 367) and point the reader to Lubow et al. (1982) who observed latent inhibition in 10- to 11-year-old children when the concurrent task required children to construct a word from scrambled letters that were printed upon the preexposed stimuli (circles). This form of concurrent task is therefore a type (a) task as it employs stimuli (scrambled letters) distinct from the stimuli to be used in subsequent training (which involved circular stimuli). Interestingly, Lubow, Caspy, and Schnur report that latent inhibition was not observed in children who did not engage in a masking task during preexposure with the same stimuli. It is arguable, however, that in the Lubow, Caspy, and Schnur study, the group that was described as receiving "no masking task" were in fact engaging in a concurrent task as they were instructed to look at the preexposed stimuli—that is, they were required to perform a task during preexposure—and in this case it was a type (b) task that directly involved the stimuli that would subsequently be presented during training. Finally, the study reported by McLaren et al. (2021), which did not observe latent inhibition in older children, can be classified as employing a type (a) concurrent task during preexposure, as children were required to differentially respond to stimuli (pictures of animals and dinosaurs) that were not subsequently presented during training. To summarize, then, latent inhibition has now been observed in older children with both a type (a) concurrent task (Lubow et al., 1982) and a type (b) concurrent task (the current study). At the same time, the absence of latent inhibition has been observed in older children with both a type (a) concurrent task (Kaniel & Lubow, 1986; McLaren et al., 2021) and a type (b) concurrent task (Lubow et al., 1982). Consequently, if, as Kaniel and Lubow suggest, latent inhibition is only observable in older children under "special masking conditions" then, for the moment, it remains unclear what those special conditions are.

Given the complexity of interpreting studies of latent inhibition in humans, and thus the still greater challenge this introduces for understanding its relationship with childhood development, it is useful to consider the effect of age on latent inhibition in nonhuman animals, where confounds associated with concurrent, or masking, tasks during preexposure are lessened. Like the study of latent inhibition in developing children, studies of latent inhibition in developing rats show some heterogeneity of results. However, there are least three published studies showing a comparable pattern of results to that described in the current experiment (Nicolle et al., 1989, Experiment 1; Rudy, 1994, Experiment 1; Hoffmann & Spear, 1989); that is, the presence of latent inhibition in older rats, and either the absence of the effect, or a parameter-dependent effect, in younger rats. Nicolle et al. (1989, Experiment 1) described a flavor-aversion study in which groups of rats aged either 18, 25, or 32 days old received pairings of a coffee solution with lithium chloride following preexposure or nonpreexposure to the solution. The results revealed that latent inhibition emerged with development: coffee-solution consumption was greater in the preexposed than the nonpreexposed rats at the age of 32 days, but there were no differences between the preexposed and nonpreexposed rats aged either 25 or 18 days. Experiment 1 reported by Rudy (1994) showed a similar developmental pattern. Rats aged either 18 or 23 days old were given a single trial in which a clicker conditioned stimulus (CS) was paired with footshock, 24 hr after 20 clicker preexposures in the same context to conditioning, a different context to conditioning, or after no preexposure. For the 23 day-old-rats, there was a clear latent inhibition effect which was also context specific—there was significantly less

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[3] The term "masking task" implies that the task in some way disguises the purpose of preexposure from the participant—an assumption which may or may not be justified. Therefore, we prefer the term "concurrent task," which carries with it fewer assumptions and simply describes the presence of another task during preexposure.

freezing in the preexposed-same condition than in either the preexposed-different or nonpreexposed condition. However, irrespective of context, preexposure had no effect on freezing behavior in the 18-day-old rats. Interestingly, In Rudy's Experiment 2, however, in which preexposure and conditioning took place on the same day, latent inhibition was observed in both the 18- and the 23-day-old rats. Hoffmann and Spear (1989), using an olfactory aversive-conditioning procedure, gave 10- or 18-day-old rats 0, 15, or 45 preexposures to an odor prior to conditioning where the odor was paired with footshock. In a subsequent spatial odor preference test between the conditioned and a novel odor the 18-day-old rats, preexposed for either 15 or 45 trials showed impaired conditioning (latent inhibition). For the 10-day-old rats, however, the results depended on the amount of preexposure given—a facilitation of conditioning was observed following 15 preexposure trials, and an impairment in conditioning after 45 preexposure trials. One study that did not reveal an effect of age on latent inhibition in rats was reported by Kraemer and Randall (1992, Experiment 1). They gave 17- and 21-day-old rats trials in which a light-tone compound CS was paired with footshock after either 20 or 0 preexposures to the compound CS alone. Suppression ratios of general activity were higher in the preexposed rats than in the nonpreexposed rats (indicating latent inhibition) at both age groups. Overall, then, there is a trend for more consistent demonstrations of latent inhibition in older rather than younger rats, across a variety of conditioning procedures. What is also apparent, though, is that latent inhibition can be observed in young rats (e.g., Kraemer & Randall). To the best of our knowledge, a pattern of results that has not yet been observed in nonhuman animals is the one observed in children by Kaniel and Lubow (1986) and McLaren et al. (2021)—the loss of latent inhibition as animals age.

Despite its apparent simplicity, latent inhibition continues to be a challenge to understand. Its theoretical basis, method of study and experimental properties are all many and varied. It is perhaps no surprise, then, that describing its relationship with age is similarly challenging. As Byrom et al. (2018) note, studies of latent inhibition in animals have provided important insights into cognitive and behavioral flexibility; and yet developing a translation of the phenomenon to humans that is both simple and free of confounds still eludes us. Consequently, the current study provides only "a" developmental trajectory of latent inhibition. As procedures for investigating the effect become more refined, we can look forward to ultimately determining "the" developmental trajectory of latent inhibition.

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