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Learning about germs in a global pandemic: Children's knowledge and avoidance of contagious illness before and after COVID-19

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ABSTRACT

The present research investigates how a global pandemic may be affecting children's understanding of contagion. In Study 1, 130 parents (85.4 % White, 6.9 % Hispanic, 3.8 % Asian, 3.8 % Black) of children ages 3–9 described discussions surrounding contagion pre- and post-pandemic. Content of these discussions focused on risks and preventative behaviors rather than causal mechanisms of contagion. In Study 2, US children tested during the pandemic (ages 4–7, N = 60, 51.7 % males) were compared to a sample tested before the pandemic (ages 4–5, N = 30, 50 % males) on tasks of contagion-related declarative knowledge and causal reasoning. Greater declarative knowledge and causal reasoning in the pandemic sample suggests the effectiveness of informal learning experiences in young children.

1. Introduction

Children's understanding of contagion (i.e., the transmission of illness through proximity or physical contact) has been a particularly fruitful area for studying causal learning in early childhood, as it has implications for how children acquire biological knowledge and for how they reason about non-obvious properties and mechanisms (Keil, Levin, Gutheil, & Richman, 1999; Au, Sidle, & Rollins, 1993; Kalish, 1996). A large body of research suggests that children's reasoning about illness begins to develop in the preschool years. For example, 4-year-olds can provide physical explanations for what makes someone sick, indicating that they have some knowledge of the association between illness and contact (Legare, Wellman, & Gelman, 2009). However, studies examining a wider age-range suggest that a full understanding of illness transmission develops in a piecemeal fashion and is only organized into a coherent conceptual framework once children have acquired an understanding of the complex biological processes that underlie illness transmission. Thus, although young children have some knowledge of risk behaviors and contaminants like germs, children do not develop a coherent causal theory about illness transmission until about middle childhood (e.g., Kalish, 1996; Keil et al., 1999; Legare et al., 2009; Myant & Williams, 2005).

Researchers have explained this developmental change by proposing that children's early understanding of contagion is based on an intuitive biology from which they are able to make very simple assumptions about illness transmission (Shtulman, 2017). For example, using simple forced choice paradigms, preschool-aged children demonstrate some knowledge that "germs" cause illness, that

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germs are living, biological entities (Kalish, 1996), and they prefer biological explanations for illness to social ones (Springer & Ruckel, 1992), demonstrating that they have some basic intuitions about how illness is transmitted. Between the ages of 7 and 11, these intuitive theories are reorganized into a more sophisticated biological framework (Myant & Williams, 2008) that supports more accurate scientific reasoning, likely as the result of formal schooling.

However, despite the fact that children do not seem to have sophisticated causal knowledge about illness transmission until the age of 7 or 8, children may be capable of learning causal biological theories at much earlier ages. Indeed, even preschool-aged children demonstrate an understanding of causal relationships across various domains, demonstrating the potential for training (Blacker & Lobue, 2016; Bonawitz, Ullman, Bridgers, Gopnik, & Tenenbaum, 2019; Bonawitz, Fischer, & Schulz, 2012; Coley, 2012; Conrad, Kim, Blacker, Walden, & LoBue, 2020; Daubert, Yu, Grados, Shafto, & Bonawitz, 2020; Flavell, Green, Flavell, Harris, & Astington, 2019; Gelman & Wellman, 1991; Gopnik & Meltzoff, 1997; Inagaki & Hatano, 1993; Kalish, 1996; Perner, 1991; Schulz, Bonawitz, & Griffiths, 2007; Shultz, 1982; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Further, one recent study even showed that children as young as five can learn about a topic as complex as natural selection by providing them with causal information in an informal picture book interaction (Kelemen, Emmons, Seston Schillaci, & Ganea, 2014). This work, combined with evidence that early childhood is a period of rapid theory change and cognitive development (Carey, 1985; Gopnik & Meltzoff, 1997; Gopnik & Wellman, 1992; Keil, 1989; Murphy & Medin, 1985; Wellman & Gelman, 1992), suggests that the preschool years may be an optimal time to begin training children with a coherent causal framework for various biological processes.

Nonetheless, development and training of a causal theory of contagion can be particularly problematic in the preschool years before formal schooling begins. Typical educational interventions may fail because they are not targeted to the attention span of preschoolers. Younger children may benefit from more informal learning interventions, such as conversations with a parent. Indeed, past research has demonstrated that children's knowledge, attitudes, and beliefs about disgust and illness are influenced by those of their parents (Sigelman, Derenowski, Mullaney, & Siders, 1993; Sigelman, Mukai, Woods, & Alfeld, 1995; Stevenson, Oaten, Case, Repacholi, & Wagland, 2010; Toyama, 2016). Recently, researchers have advocated using explanation-based instruction to teach complex counterintuitive concepts to young children (Conrad et al., 2020; Kelemen, 2019; Kelemen et al., 2014; Myant & Williams, 2008). Findings from such research suggest that causal knowledge about illness transmission might be an important mechanism that leads to healthy behavior in preschool-aged children, and that even 3- to 5-year-olds can learn a causal explanation for illness transmission from a simple informal learning experience (Conrad et al., 2020).

Given the social and economic burden of the recent COVID-19 pandemic, providing children with causal knowledge of illness transmission in particular is more important than ever, as it has implications for the development of health-related behaviors. Due to a variety of immunological, ontological, and behavioral factors, children can act as a reservoir for contagious illnesses. Unfortunately, most local and national strategies designed to eliminate the spread of illnesses among young children, such as closing schools to eliminate contact, are based on the assumption that children cannot behave in ways that prevent them from getting sick and from spreading illness to others (e.g., Koonin & Cetron, 2009). However, research suggests that causal knowledge of how illnesses are spread can be a potential mechanism that might underlie the development of disease-avoidant behavior (Siegal, Fadda, & Overton, 2011). More specifically, two studies have now demonstrated that children who have a more sophisticated causal understanding of illness transmission are more likely to avoid proximity to a sick person and contact with a contaminated object (Blacker & Lobue, 2016; Conrad et al., 2020). Thus, examining whether and how younger, preschool-aged children acquire causal knowledge of illness transmission in a way that relates to their adaptive avoidance of contamination is an important topic for research.

The recent COVID-19 pandemic has created a unique opportunity to examine the impact of informal learning experiences on children's knowledge about illness transmission and their subsequent behavior. It is possible, for example, that given recent social distancing guidelines, parents are talking to their children about illness transmission more than ever before. These informal conversations may facilitate the transmission of illness-related information, and therefore increase children's causal knowledge of illness transmission, relevant to both COVID-19 and contagious illness in general, as transmission is similar across many pathogens. Here, we ask whether parents are frequently talking to their children about illness transmission at home in light of the COVID-19 pandemic, with the goal of characterizing how the pandemic has shaped informal learning experiences for young children (Study 1). We then compare children's knowledge about illness transmission and contamination avoidance in two samples—one tested during the first six months of the US pandemic, and one serendipitously tested immediately prior (Study 2). The findings have implications for the design and implementation of future contagion-related interventions for young children in informal learning environments.

2. Study 1

Previous research has demonstrated that while understanding causal mechanisms of contagion may be important for promoting adaptive avoidance behavior, very few preschoolers have acquired this knowledge (Blacker & Lobue, 2016; Conrad et al., 2020). Additionally, little is known about how parents discuss contagious illness with their young children. In the context of the COVID-19 global pandemic, it is possible that parents' conversations with their children about contagion have increased. The goal of Study 1 was to characterize how parents discuss contagion with their young children, and how the pandemic has affected those discussions and their associated behaviors.

2.1. Method

2.1.1. Participants

Parents of children aged 3–9 years (M = 5.4 years) were recruited to participate in an online survey from a link on social media (e.

g., Facebook and Instagram), that was posted by our laboratory and shared openly by individuals and within parenting groups. If parents had multiple children within the age range, they were asked to complete the survey for only one child closest to the age of 5 (on average, parents reported two children per household). Sixty-eight percent of all participants reported for preschool-aged children (ages 3–5). One-hundred and forty-eight participants completed the questionnaire, and 17 participants were excluded from analysis due to children's reported ages falling outside the requested range. The final sample included 130 adults from all over the United States (92 % female, 85.4 % White, 6.9 % Hispanic, 3.8 % Asian, 3.8 % Black, 72 % with advanced degrees, and 65 % with annual incomes over \$100,000).

2.1.2. Procedure

The online survey was originally posted in the last week of March, 2020. Data were collected over a period of two weeks. Parents were asked open-ended questions that prompted them to describe how they discussed contagious illness with their children prior to the pandemic, how/if they discussed COVID-19 with their children, and also how/if that conversation had changed since the pandemic began. No specific time range was specified in the survey for respondents to allow for regional differences in the onset of pandemic. The survey included additional questions about health-related behaviors, beliefs, and emotions. Only the subset of responses specific to illness reasoning and avoidance behavior was analyzed here (full questionnaire available in Appendix and on Databrary). Using a 5-point scale (completely disagree to completely agree), parents reported on their confidence in their child's (1) understanding of how to avoid illness and (2) the likelihood their child would *actually* avoid a potential health risk (e.g., playing with a sick child). Additionally, social distancing practices were probed by asking parents to select one of four options ranging from none to strict: (1) We choose not to separate from others nor to limit our activities, (2) We only interact with extended family and a small social circle (e.g., individual playdates, babysitters), (3) We only interact with people in our extended family, and (4) We only interact with people in the immediate family with whom we share a home.

2.1.3. Coding

Parent reports of contagion-related discussions prior to and during the pandemic were coded based on five categories (see Table 1): (1) risk behaviors and preventative measures, (2) biological terms (e.g., germs), (3) causal mechanisms of illness transmission, (4) affirmation of discussions about contagion with no specific details of discussion content, and (5) no discussion of contagion. Categories 1–3 were not mutually exclusive. Additionally, descriptions of discussions about contagion in the context of the novel coronavirus were coded for the presence of social distancing language (e.g., "stay at home," "stay away from others," "keep distance"). Analyses are based on a primary coder's classifications. An independent second coder also classified all responses to establish reliability, achieving an average Cohen's kappa of 0.81.

2.2. Results and discussion

Almost all parents (96.9 %) reported talking to their children about illness transmission in light of the COVID-19 pandemic. While most parents discussed contagion previously (91.5 %), 65.3 % of parents reported increases in rate and depth of discussion surrounding contagion, as a result of the pandemic. These rates did not differ for parents of younger and older children (Chi-square p's > 0.5), and even 67 % parents of preschool-aged children (3–5 years) reported increasing contagion discussions, suggesting that parents consider learning about contagion to be important and appropriate for preschoolers as well as school-aged children.

Interestingly, despite reported increases in discussions as a result of the pandemic, the content of those discussions was similar (see Table 1). Prior to the pandemic, 72.3 % of parent reports were coded as mentioning risks and preventative measures, 46.9 % biological, 21.5 % causal mechanisms, and 6.9 % were classified as affirming discussion of contagion without any specific content of their discussion. When discussing the novel coronavirus, 72.7 % of parents were coded as mentioning risks and preventative measures, 39.1 % biological, 7.8 % causal mechanisms, and 17.2 % nonspecific. Parents also reported that additional contagion-related knowledge was obtained through school/daycare programs (75 %), books (30 %), and television programs (30 %).

Although most parents reported discussing contagion with their children, only 59 % of parents reported that their children had a strong understanding of how to avoid illness (mean confidence rating = 3.7, SD = 0.98), and merely 5% of parents believed their child would actually *behave* in ways that would keep them from exposure (e.g., avoid playing with a sick friend; mean confidence rating = 2.1, SD = 1.24). Children's avoidance behavior might be supported by increased understanding of the causal mechanisms of transmission, given that research shows that interventions emphasizing causal mechanisms of contagion support adaptive behavior,

Table 1

Categorical Coding of Parent Discussions about Contagion Illness. General refers to general conversations about contagion prior to the pandemic (N = 130) and coronavirus refers to parental descriptions of conversations specific to the novel coronavirus (N = 128, 2) participants did not complete this question). All values reflect the percent of responses coded for each category. The first three columns are not mutually exclusive.

| | Risk/ Prevention | Biological | Causal | Yes- Unspecific | No Discussion |
|------------------------|--|--|---|----------------------------------|---------------------------------------|
| Example language | Explained importance of hand washing and keeping distance from others during this time | Germs are invisible bugs that can make people very sick. | Germs are in our nose and mouth and on our hands. Whatever we touch we leave germs on, and pick up other people's germs too. | People are sick and need rest | We haven't really discussed it. |
| General Coronavirus | 72.3 72.7 | 46.9 39.1 | 21.5 7.8 | 6.9 17.2 | 8.5 3.1 |

whereas educational interventions focusing on risk/preventative measures do not impact knowledge or behavior (Au et al., 2008; Blacker & Lobue, 2016; Conrad et al., 2020). The disconnect between knowledge and adaptive behavior might be due to the fact that parents' reports of discussions with their children centered around risk prevention strategies only, rather than biological explanations or causal mechanisms of illness transmission. Interestingly, 62.5 % of parents spontaneously reported discussing social distancing with their children, demonstrating the emphasis of physical proximity in contagion-related discussions during the pandemic. This number may have been an underestimate of the extent of discussions surrounding social distancing, as 90 % of all respondents reported engaging in the highest degree of social distancing, only interacting with people in the immediate family with whom they share a home.

Collectively, these results indicate that the COVID-19 pandemic presented most families in our sample with the opportunity to discuss contagion and illness transmission to a greater extent than ever before. Our ability to interpret these data are somewhat limited due to reliance on retrospective parental self reports to open-ended questions that were intentionally general to allow parents to freely respond without constraints, but which consequently, produced descriptive rather than inferential data. As a result, the frequency of types of information discussed by parents may not be accurately reported. Additionally, the results may not be generalizable across a more racially and socioeconomically diverse population than was sampled in the current study. Nonetheless, understanding the nature of the discussions families are having with young children can help us examine how the pandemic may serve as a simulation of an informal learning intervention for contagion knowledge and reasoning. If parents (such as participants in Study 1, and others more generally) are talking more about contagion to their children as a result of the pandemic, and if informal learning experiences can produce greater declarative and causal knowledge about contagion (Conrad et al., 2020), then we would expect children tested during the pandemic to demonstrate greater declarative knowledge and causal reasoning about contagion than their same age peers tested prior to the pandemic. Study 2 addresses this question.

3. Study 2

The goal of Study 2 was to investigate whether young children have explicit declarative knowledge about contagion as well as causal reasoning about illness transmission, and whether knowledge about contagion differed based on the onset of the 2020 global coronavirus pandemic. We began collecting data for a study in 2019 designed to replicate and extend previous findings (pre-registered at aspredicted.org #23364). The sudden changes necessitated by the global pandemic of Spring 2020 created an environment in which families were forced to significantly change behaviors and potentially increase discussions about contagious illness. This created a natural experiment, which we attempted to explore in the current study (pre-registered at aspredicted.org #40204).

In Study 2, we compared a sample of children tested during the pandemic (ages 4-7, N = 60, 51.7 % males) to a sample of children tested before the pandemic (ages 4-5, N = 30, 50 % males) on tasks of contagion-related declarative knowledge and causal reasoning. To examine how knowledge is related to behavior, we also presented the pandemic sample with a behavioral choice task where we asked them to choose between a contaminated versus uncontaminated toy. We asked whether children's contagion knowledge after the onset of the pandemic was greater than children's contagion knowledge directly prior, and whether children's knowledge was related to avoidance behavior.

3.1. Method

3.1.1. Participants

3.1.1.1. Pandemic sample. Parents of children aged 4–7 years were recruited via social media and digital listservs from across the country between May and August 2020. Advertisements were posted on social media (e.g., Facebook and Instagram) and www. childrenhelpingscience.com. Additionally, because our prior research samples consisted entirely of children in preschools from the racially and socioeconomically diverse Essex County in NJ, local families in our research database were emailed to participate in our online study as well in an attempt to match our samples. Of the 1000 local eligible families invited to participate, only 12 participated in the current study. We ensured that no children participated in both Study 1 and Study 2, as there was no way to avoid response bias if families participated in both studies. Based on prior work that suggests preschoolers have some declarative, but incomplete causal knowledge of illness transmission (Blacker & Lobue, 2016; Kalish, 1996; Legare et al., 2009; Myant & Williams, 2008), we compared younger children (4- and 5-year-olds) to older children (6- and 7- year-olds) in our pandemic sample, to demonstrate whether we could replicate previous developmental effects in an online adaptation of the contagion knowledge assessment. Seventy-six children participated in the online study. Sixteen children were excluded from analyses due to: child's inability to speak English (N = 2), failure to pass attention check (N = 5), and technical issues (N = 9). This resulted in a final sample of 30 children aged 4–5 (14 males, M = 4.96yrs) and 30 aged 6–7 (16 males, M = 7.2yrs) in our pandemic participant group. Parents of this cohort were 68.3 % White, 15 % Asian, 6.7 % Hispanic, 1.7 % Black (8.3 % not reporting), 86.7 % college-educated, and 68.3 % reported annual income over \$100, 000.

3.1.1.2. Pre-pandemic sample. Thirty participants between 4- and 5- years of age (15 males, M = 4.8yrs) were recruited from preschools and the community in Essex County, NJ between July 2019 and January 2020. Parents of this group did not directly report income and education, so SES of families was estimated based on census data of median income and education rates of families' reported zip codes. Based on those estimates, parents of this cohort had an average income of \$92,610 and approximately 53 % were college educated. There were no significant differences between these zip-code based estimates and census data from zip codes of the pandemic sample participants (average median income \$84,000 and college education rate is 50 %), though this does not guarantee that the samples are completely SES matched, as the online pandemic sample did report higher rates of education and income than those estimated based on the zip codes. Additionally, partial reports of race/ethnicity in the pre-pandemic sample suggest that it is more diverse than the pandemic sample. Only 53 % of parents reported race/ethnicity: 23.3 % identified as Hispanic, 16.7 % as White, 6.7 % as Asian American, and 6.7 % as Black.

3.2. Measures

Participants gave written consent for their child's participation and children were asked for verbal assent. For the pre-pandemic sample, children were tested in person with a researcher presenting stimuli on a computer screen and on paper. For the pandemic sample, a researcher directed the study over videoconferencing (Zoom) and all stimuli were presented online via Qualtrics (stimuli examples available on Databrary).

3.2.1. Declarative knowledge task

Declarative knowledge of contagious illness refers to the verbal explanations about sickness, and does not make any assumptions about comprehension. For example, a child may be explicitly taught simple associations between germs and sickness, but not fully understand the mechanisms underlying this relationship. To assess children's declarative knowledge of contagion, we used a vignette task previously reported by Blacker and Lobue (2016). Children were read two short vignettes about photos of children (neutral faces from CAFE dataset, LoBue & Thrasher, 2015) described as having a contagious illness (cold) and a non-contagious illness (toothache) and were asked an open-ended question about how the child got sick/toothache (illness explanation), and whether another child or the participant could get sick by interacting with the child with the cold/toothache (illness prediction). For the cold vignette, they were shown a picture of a child and were told, "This is Sal. Sal has a cold, so Sal has a runny nose, a headache, and sore throat." For the toothache vignette, they were shown a picture of a different child and were told, "This is James. James has a toothache. He has trouble eating because his tooth really hurts."

3.2.2. Illness avoidance task

Following the knowledge task, an illness avoidance test was administered. This test measures children's avoidance of objects that had previously been used by a child with a contagious illness. Participants were told that the two children from the illness vignettes described above had played with toys earlier in the day. The photographs of the children and two identical toys (slinkies) were displayed on the screen. The participant was asked to choose which toy he/she would rather play with. Immediately after this choice, the participant was asked to indicate which of the two children was sick with a cold as an attention and memory check. Participants' choices were scored as 0 (cold) or 1 (toothache). A subset of children in the pre-pandemic sample (N = 14) participated in a similar, though non-identical avoidance task (similar to Blacker & Lobue, 2016). Due to the small sample size in the pre-pandemic sample, as well as discrepancy in methods, behavioral avoidance could not be meaningfully compared across samples.

3.2.3. Causal reasoning task

For the current study, we defined causal reasoning as the flexible use of a theoretical framework to generate explanations, make predictions, and inform decision-making about how to interact with sick individuals and contaminated objects. To determine how children used causal frameworks to reason about illness transmission, we developed a task in which participants were presented with a series of vignettes where characters are exposed to illness with varying degrees of (1) duration of exposure to a sick individual (Duration Vignette) (2) proximity to a sick individual (Proximity Vignette) and (3) number of transfers of germs between sick individual and target (Transfer vignette). Exposure time was varied to examine if children associate prolonged exposure to a sick person (as opposed to brief exposure) with higher likelihood of contracting illness. Proximity was varied in another scenario to assess whether children associate a shorter distance from a sick person's sneeze with a greater likelihood of illness contraction. We varied the number of times germs were transferred from a sick person (e.g., via cough) to various contact points, to assess whether children can understand that illness is transferred via invisible germs that can live on surfaces but dissipate with increasing transfers.

These three types of causal reasoning, though not an exhaustive list of potential models, were chosen as possible theoretical frameworks for understanding illness transmission for several reasons: (1) they are consistent with predominant modes of illness transmission (droplets, contact, and aerosols) and epidemiological models of illness transmission (e.g. Atkinson & Wein, 2008; Health & Human Services Department, U.S. Government, 2004); (2) they are consistent with intuitive causal models of dissipation effects studied in other biological domains (e.g. White, 2000); and (3) similar vignettes piloted in adults revealed systematic causal reasoning reflecting sensitivity to temporal, proximal, and contact exposure influencing the probability of transmission. Vignettes were narrated along with animated visual displays, introducing three characters at different states of exposure risk (matching gender to the participant). In addition to the three characters presented in each story, an irrelevant lure character was used as the 4th choice option in each vignette. Children were asked to choose which one of four characters was most likely to get sick while the displays were still visible, so that the task did not require excessive memory demands. After making an initial selection, children were told that a second character also got sick and were asked to choose whom they think is most likely to get sick. This second choice allowed us to determine if participants are using systematic causal inference to make their selections. Finally, an attention/memory check was asked for each vignette to make sure the child was able to follow the details of the story. Detailed descriptions of each vignette are provided here; content in the parentheses was not read to the children:

Duration vignette: At the end of the school day, Sam starts to feel sick. Sam has a fever, a cough, runny nose and a stomachache. Sam has to wait a very long time before she can get off the bus because her house is the very last stop. Quinn does not ride the bus home with the other kids, so she is already home from school (lure). Soon after the bus leaves, Blake gets off the bus (lowest risk). The bus keeps driving for another ten minutes and then Taylor gets off the bus (medium risk). The bus drives a little more and after 20 min Jordan gets off the bus (highest risk). Finally, Sam gets off the bus. So, remember, the bus dropped off Blake, then Taylor, then Jordan and finally Sam. The next day, one of Sam's friends gets sick. Who do you think gets sick? Another friend also got sick - who else do you think got sick? Who got off the bus first?

<u>Proximity vignette</u>: This is Morgan. He is sick with the flu. As he is walking down the hallway at school, Morgan sees his friends walking toward him. As he is walking toward his friends Morgan feels like he has to sneeze. ACHOO! Morgan forgets to cover his mouth and accidentally sneezes everywhere. Max is 1 foot away (highest risk). Bobby is 5 feet away (medium risk). Charlie is 10 feet away (lowest risk). Sasha was not in the hallway when Morgan sneezed (lure). The next day, one of his friends from school gets sick with the flu. Who do you think got sick? Another friend also got sick. Who else do you think got sick? Who was closest to Morgan when he sneezed?

Transfer vignette: Alex wants to play with her friends, but she is so sick and has a really bad cough. She sees some friends getting ready for snack. Alex's friend Sawyer puts out a hand to give Alex a high-five, but then Alex coughs all over Sawyer's hand. Alex is too sick for snack and leaves to see the nurse. Sawyer sees her friend Frankie (highest risk), so she gives her a high five. Frankie sees her friend Chris (medium risk) and gives her a high five. Chris sees her friend Jesse (lowest risk) and gives her a high five. So, remember, Sawyer high fived Frankie and then Frankie high fived Chris and then Chris high fived Jessie. Their other friend Pat did not give a high five, but he joined in for snack along with Frankie, Chris and Jessie. The next day one of the friends got sick with a bad cough. Who do you think got sick? Another friend also got sick. Who else do you think got sick? Who got the last high five?

3.2.4. Coding

3.2.4.1. Declarative knowledge coding. Children's explanations about how the child got sick were coded according to the schema described previously (Blacker & Lobue, 2016). Responses were coded as contagion-relevant if they included explanations related to any of the following: (a) risk behaviors (e.g., "touching something dirty and putting hands in his mouth") (b) failure to engage preventative measures (e.g., "not washing his hands"), (c) proximity to a sick individual (e.g., "by being close to another person who got sick"), or (d) biological terms (e.g., "from spreading germs"). Responses were coded as contagion-irrelevant if they did not fall into the above categories (e.g., "from not zipping up his jacket" or "I don't know"). Analyses were based on the primary blind coder, and a secondary coder also categorized explanations to achieve substantial reliability with a Cohen's Kappa = 0.81. Illness prediction questions were coded as 1 for correct response ("yes" for cold and "no" for toothache) and as 0 for incorrect responses ("no" for cold and "yes" for toothache).

3.2.4.2. Causal reasoning coding. In each vignette, participants indicated which character got sick from an array of four choices. Selection of the highest-risk option in each vignette was coded as 1; all other responses were coded as 0. Additionally, to determine the systematicity of responses within each vignette, we analyzed who the child selected as the most likely and second most likely to get sick by using a weighted scoring system. Each character in a vignette was assigned a value based on how high their risk of infection was: highest risk (3), medium risk (2), lowest risk (1), and irrelevant lure (0). The systematicity score for each vignette was defined by doubling the score of the first choice and adding that to the second-choice score, resulting in a total vignette score between 1-8. A total score causal prediction score was calculated as the sum of the three individual vignette scores. Data was missing from one child in the composite score analyses due to refusal to answer secondary questions in the causal prediction task.

3.3. Results and discussion

We ran several sets of planned analyses. Previous work demonstrated that contagion-related causal knowledge increases with age (Blacker & Lobue, 2016). Thus, we first examined age related differences in children's knowledge (both declarative and casual) and behavior in the pandemic group. The results will tell us whether we were able to replicate the findings of previous studies using the same set of tasks (i.e., Blacker & Lobue, 2016), and whether our virtual paradigm provides results that are comparable to those using in-person testing. Next, we compared the younger children in the pre-pandemic and pandemic samples on the declarative and causal knowledge tasks to examine whether children in the pandemic group, who were likely exposed to more verbal information about illness transmission, demonstrate more knowledge than children in the pre-pandemic group. In one final set of analyses, we asked whether children's knowledge in the pandemic sample was related to behavioral avoidance of a contaminated toy.

All analyses on the causal reasoning task were first run using children's first choice score on each task, and then run on their composite scores, which (as described above) include both children's first and second choice and represent the systematicity of children's reasoning. It is important to note that a large proportion of children failed the memory/attention checks for this task: 50 % for Duration, 15 % for Proximity, and 7% for Transfers. The high failure rate for the Duration vignette in particular may be due to the fact that this question requires the children to remember content that is inconsistent with the visual display, thus leading many children to choose the lure. As a result, we included all participants' data in the analyses below to maintain statistical power. However, effects of our planned analyses remained unchanged when we included only participants who passed the attention check for the

respective vignette.

3.3.1. Age effects on contagion knowledge

Our first question was whether we replicated the age-related differences reported previously on the development of contagionrelated knowledge and avoidance behavior in the pandemic cohort tested online (Blacker & Lobue, 2016). All results are summarized in Table 2 and Fig. 1. Chi-square tests were performed to examine the relation between age and explanation type (contagion-relevant or contagion-irrelevant) and illness prediction ability in the declarative knowledge task, and avoidance of the contaminated toy in the illness avoidance task. Consistent with previous 'in lab' results, younger children in the online sample were less likely than older children to correctly provide contagion-relevant explanations, $\chi^2(1, N = 60) = 5.08$, p = .024, to correctly answer the illness prediction question, $\chi^2(1, N = 60) = 11.88$, p = .001, and to avoid the contaminated toy, $\chi^2(1, N = 60) = 6.41$, p = .011. These age effects replicate those found previously using similar or identical measures collected in-person (Blacker & Lobue, 2016) and the overall rates of illness prediction success were comparable to those reported in previous research. The rates of contagion-relevant explanations and behavioral avoidance were somewhat higher in the current sample in both younger and older children than previously observed by Blacker and Lobue (2016), potentially reflecting differences in the measures (behavioral avoidance), the samples, or the circumstances of the pandemic. Overall, however, these results suggest that the online versions of our tasks administered via Zoom produced comparable results to previous data collected live.

To determine if causal reasoning about illness transmission changes with age, we performed additional chi-square analyses comparing the first-choice responses identifying the highest risk option on each of the three causal knowledge vignettes (duration of contact with a sick person, proximity to a sick person, and number of intermediates between the sick person and the target) across our two age groups. Older children chose the highest risk option in the causal reasoning vignette probing temporal delay, $\chi^2(1, N = 60) = 6.787, p = .009$, and in the vignette probing number of germ transfers, $\chi^2(1, N = 60) = 11.279, p = .001$, but there was no significant difference across the age groups for the proximity vignette, $\chi^2(1, N = 60) = 2.963, p = 0.85$, likely because of a ceiling effect on this task.

As described above, composite scores on each causal knowledge vignette provided us with an enhanced measure of systematic causal reasoning that we could compare across age groups using independent t-tests (see Fig. 1, Bottom). Total composite scores across all three vignettes did not differ significantly between younger (M = 17.48) and older (M = 18.77) participants, t(57) = 1.30, p = .20. Comparing scores on individual measures also did not reveal statistically significant differences. Composite scores were marginally higher for older children on the Duration vignette, t(57) = 1.80, p = .078, but did not significantly between groups differ for the Number of Transfers vignette, t(57) = 1.04, p = 0.302, suggesting that even though older children were more likely to choose the highest-risk answer choice for both of these vignettes, they were not more systematic in their responses overall (or they adopted alternative theoretical frameworks to those being evaluated). However, the comparison did reveal a significant difference between age groups on the composite scores for the Proximity task, t(57) = 2.086, p = .041, suggesting that compared to younger children, older children better understood that risk of infection increases monotonically as distance between people decreases. However, further inspection of the proximity data revealed that the proximity composite scores were not normally distributed (a requirement of a *t*-test

Table 2

Children's Performance on Contagion Knowledge Measures.

| | Pre-pandemic | Pandemic | | |
|---|--|---------------------------------------|-------------------------------------|--|
| Age in years: M (SD) | Younger (4–5 year olds) 4.78 (0.54) | Younger (4–5 year olds) 4.96 (.52) | Older (6–7 year olds) 7.21 (.55) | |
| Declarative Knowledge | | | | |
| Contagion-relevant explanations (%) | 28 | 57 | 83 | |
| How did he get sick with a cold? | | | | |
| Causal Prediction | | | | |
| Illness Prediction Accuracy (%) | 73 | 60 | 97 | |
| Would you get sick by playing with him? | | | | |
| Avoidance Behavior | | | | |
| Chose non-contaminated toy (%) | | 73 | 97 | |
| Causal Reasoning Duration | | | | |
| Chose Highest Risk Option (%) | 37 | 40 | 73 | |
| Causal Reasoning Proximity | | | | |
| Chose Highest Risk Option (%) | 47 | 83 | 97 | |
| Causal Reasoning Transfers | | | | |
| Chose Highest Risk Option (%) | 17 | 30 | 73 | |
| Causal Reasoning Duration | | | | |
| Composite Score: M (SD) | 5.17 (1.97) | 5.28 (2.30) | 6.43 (2.64) | |
| Causal Reasoning Proximity | | | | |
| Composite Score: M (SD) | 5.2 (2.43) | 7.31* (1.71) | 7.97 (.18) | |
| Causal Reasoning Transfers | | | | |
| Composite Score: M (SD) | 4.53 (2.33) | 4.9* (2.38) | 4.33 (1.73) | |
| Causal Reasoning Total | 14.90 (4.51) | 17.48* (4.11) | 18.77 (3.46) | |
| Composite Score: M (SD) | | | | |

N = 29. Otherwise N = 30 for all cells.



Younger(4-5) Older(6-7)



Fig. 1. Age Effects on Knowledge and Behavior in the Pandemic Group. (Top) Relative to younger children (4-5 years), older children (6-7 years) demonstrated greater declarative knowledge (biological explanation in response to question, "How did he get sick?"), illness prediction (participant predicted he/she could get sick by playing with a sick child) and avoidance of a contaminated toy. (Bottom) Causal reasoning composite scores on the proximity, duration and transfer vignettes did not significantly differ between younger and older participant groups. Proportion of participants passing (scoring above 4) is displayed for proximity (nonparametric comparison) and boxplots of composite scores are displayed for duration and transfer (possible scores between 1-8). For the proximity vignette, no error bar is displayed for the older participants because 100 % of participants ages 6-7 passed the proximity task. For the transfer vignette, no box is visualized for the older group because greater than 75 % of the sample scored at the median value of 4.

for assumptions to be valid.) A non-parametric comparison, splitting children who failed the test (scoring less than half the total possible) to children who passed (scoring more), did not reveal a difference between age groups in the pandemic sample, Fisher's exact, p = .11.

3.3.2. The impact of the pandemic on children's knowledge

To examine whether the pandemic was related to children's knowledge about contagious illnesses, we ran a series of analyses comparing the younger group sample from the pandemic group to a pre-pandemic sample (see Table 1 and Fig. 2, Top). Age of

participants in the pandemic sample (M = 4.96, SD = 0.52) was not significantly different from the pre-pandemic sample (M = 4.78, SD = 0.54). For the declarative knowledge tasks, chi-square analyses indicated that children in the pandemic group more frequently provided contagion-relevant explanations than children in the pre-pandemic group, χ^2 (1,N = 60) = 4.34, p = .037. However, we found no significant differences between the two cohorts on illness prediction ability, χ^2 (1,N = 60) = 1.2, p = .273.

In the causal reasoning task, relative to children in the pre-pandemic group, those in the pandemic group were more likely to correctly identify the highest risk choice in the proximity vignette, $\chi^2(1, N = 60) = 8.864, p = .003$, but there were no significant differences for the other vignettes (Duration: $\chi^2(1, N = 60) = 0.71, p = .791$; Transfers: $\chi^2(1, N = 60) = 1.491, p = .222$). These results indicate that children in the pandemic group use proximity information as a cue to contagion risk, but they do not allow us to







Pre-pandemic Pandemic

Fig. 2. The Impact of the Pandemic on Children's Knowledge and Behavior. (Top) Relative to children tested before the pandemic, children tested during the pandemic had greater declarative knowledge, but no difference in illness prediction ability. (Bottom) Children tested during the pandemic demonstrated greater systematic causal reasoning about proximity than children tested prior to the pandemic, but no differences were observed for composite scores on the duration or transfer causal reasoning vignettes.

determine whether children are using a systematic approach indicative of a more complex theoretical framework, since children could be choosing the highest risk option solely based on application of a simple declarative rule. However, the composite scores provide a measure that can differentiate between responses that are simplistic or random, and those that are more systematic. Indeed, our findings support the idea that causal reasoning was greater for children in the pandemic group. Relative to those in the pre-pandemic group, children's proximity composite scores in the pandemic group (M = 7.3) revealed greater systematicity than the pre-pandemic group scores (M = 5.2, Fisher exact, as split between high (score of 5–8) and low performers (score of 1–4): p = .007). As noted above, the assumptions of a *t*-test were violated in the proximity data. However, for completeness, we report the t-statistic: t(50) = 4.29, p < .0001. In contrast, there were neither differences between composite scores on the duration vignette between pre-pandemic (M = 5.2) and pandemic (M = 5.3) groups, t(57) = .20, p = .845, nor were there differences for the number of transfers between pre-pandemic (M = 4.5) and pandemic (M = 4.9) groups, t(57) = .59, p = .56. However, the total composite score was significantly higher for the pandemic sample (M = 17.48) than the pre-pandemic sample (M = 14.9), t(57) = 2.3, p = .025, likely driven by the differences in the proximity vignettes.

3.3.3. The relation between causal knowledge and behavior in the pandemic group

Finally, we asked whether contagion-related knowledge was associated with behavioral avoidance of contaminated toys in the pandemic sample (see Table 3). To do this, we conducted chi-square analyses to determine if participants who successfully avoided the contaminated toy scored higher on each measure of contagion-related knowledge in both the declarative knowledge and causal reasoning tasks. For the declarative knowledge task, contagion-relevant explanations were not associated with avoidance behavior, χ^2 (1,N = 60) = 3.3, Fisher's exact test, p = 0.11. However, illness prediction ability was significantly related to successful avoidance of the contaminated toy, χ^2 (1,N = 60) = 19.64, Fisher's exact test p = .0014. To control for potential age effects in this analysis, we reran this test on only our youngest participants in the pandemic sample, but found the same results, χ^2 (1,N = 30) = 5.57, Fisher's exact test p = .034.

For the causal knowledge task, although the mean proximity scores for children who avoided the contaminated toy were higher (M = 7.78) than for those who did not (M = 6.75, t(57) = -2.3, p = .027), the data were not normally distributed. Thus, we used a non-parametric comparison, splitting children who failed the test (scoring less than half the total possible points) and children who passed (scoring more than half), yielding a significant difference between avoiders and non-avoiders, χ^2 (1,N = 60) = 7.61, Fisher's exact test, p = .046. The other two causal knowledge scores were not significantly related to children's avoidance scores (Duration: t(57) = 0.312, p = .756; Transfers: t(57) = .022, p = .983).

4. General discussion

The COVID-19 global pandemic has presented parents with a more urgent need to discuss contagious illness with their young children, presenting researchers with a unique opportunity to study children's learning about illness transmission as potentially influenced by these informal conversations at home. In Study 1, we found that parents did report an increase in the frequency and depth of their discussions about illness transmission with their children. However, the content of their discussions still focused largely on risks and preventative behaviors as opposed to causal mechanisms of transmission, which are known to be important for predicting adaptive behavior (Blacker & Lobue, 2016; Conrad et al., 2020). Study 2 revealed that children tested during the pandemic demonstrated greater explicit declarative knowledge and causal reasoning ability about contagion than did children tested immediately prior to the pandemic. Further, explicit declarative knowledge about illness transmission and causal reasoning about the role of proximity predicted children's avoidance behavior.

Although the experimental design does not allow for causal conclusions about the relationship between informal learning opportunities and increased contagion knowledge and reasoning, the findings provide converging evidence that these measures are cooccurring during the pandemic. While researchers have often thought that preschool-aged children have an underdeveloped theory of contagion, the current research suggests that cognitive change might be possible from informal conversations at home. Theoretically, since the onset of the pandemic, children are getting more information about illness transmission than they typically would, which they are then using to build and modify their existing biological theories, hopefully in a way that helps them more readily apply them to health behavior.

Collectively the results suggest that the circumstances of the COVID-19 pandemic increased discussions surrounding contagion (Study 1), as well as contagion-related knowledge and causal reasoning in preschool-aged children (Study 2). Consistent with previous findings (Blacker & Lobue, 2016), the results of Study 2 demonstrate that older children (6–7 years old) have an advantage over preschool-aged children (4–5 years old) in declarative knowledge, causal knowledge and avoidance behavior. It is unclear whether this age advantage is the result of developmental changes in reasoning or prior educational interventions and experience, as both studies found an association between illness prediction ability and behavioral avoidance of a contaminated item, independent of age. Interestingly, Study 2 reveals that preschool-aged children tested during the pandemic also showed an advantage in contagion-related

Table 3

Contagion Knowledge Differs in Children Who Avoid Contaminated Toys.

| | Declarative Knowledge (N correct responses) | Illness Prediction (N correct responses) |
|-----------------------------------|---|--|
| Failed to Avoid (N = 9) | 4 | 2 |
| Avoided Contaminated Toy (N = 51) | 38 | 45 |

knowledge and reasoning over their peers assessed prior to the pandemic, suggesting that knowledge gains may be attributed to education or informal learning experiences rather than other developmental changes in reasoning ability.

The specificity of improvement in causal reasoning about proximity may reflect the societal emphasis on social distancing to prevent contagious illness during this COVID-19 pandemic. Indeed, parents in Study 1 reported strict social distancing at high levels, and spontaneously mentioned social distancing language in their reports of contagion discussions with their children. Interestingly, parents did not mention language about other aspects of causal reasoning about contagion, such as exposure duration and number of contact points and dissipation of germs. Likewise, in Study 2, we did not see any differences in children's ability to causally reason about duration or contact transfer between those participating before and during the pandemic. While it is not necessarily surprising that children demonstrated enhanced performance on the one causal reasoning task related to the information that was emphasized during the pandemic, it is nonetheless an important illustration of how very young children are capable of learning to causally reason about contagion with informal educational experiences.

Alternatively, children may have performed better on the proximity reasoning task for reasons unrelated to educational interventions afforded by the pandemic; perhaps the proximity reasoning task was the most straight-forward and easily grasped concept by our youngest participants, whereas duration and transfer reasoning were more difficult. Furthermore, the causal relations tested in our causal reasoning task are certainly not the only possible beliefs that children may use to reason about contagious illness. As a result, we can only make limited inferences about how children causally reason about contagion, and future studies to more thoroughly explore this question would be beneficial. Because the current studies are correlational, we cannot make conclusions about how children would perform on these reasoning tasks with specific causal mechanism training related to these topics. Furthermore, because there are potential confounds between the pandemic's effects and differences in data collection (in person prior to the pandemic vs. online during the pandemic), interpretations of the findings may be limited. Nonetheless, these studies provide preliminary evidence that very young children can be taught to reason about contagion during informal learning experiences, such as conversations with parents.

Critically, children's understanding of and reasoning about contagion may not be helpful if they do not engage in adaptive avoidance of health risks. Unfortunately, we were unable to measure and compare behavioral avoidance of contamination between the pre-pandemic and pandemic groups due to the unforeseen circumstances of the pandemic, requiring changes to data collection procedures. However, within our pandemic cohort, explicit causal illness prediction ability was related to avoidance behavior, even in our youngest participants. Our ability to detect stronger effects of knowledge on avoidance behavior may have been limited by the observed ceiling effects on the avoidance measure used in the current study. We would expect to see more variability in real-world avoidance situations, given that most parents in Study 1 reported that they believed their child would not avoid playing with a sick child. Future research is needed to further investigate this issue.

Interpretations of our findings also may be limited because our online sample populations from the US were predominantly white and high SES. Due to the unforeseen circumstances of the pandemic, we could not completely match the online sample to our prepandemic sample, which was likely more racially, ethnically, and socioeconomically diverse, thus creating a potential limitation to the interpretations of our findings. Given that domain specific knowledge varies based on education and experience, we might expect to see different results in a more diverse sample. However, while it is possible that baseline knowledge about contagion may differ as a function of SES or race/ethnicity (Sigelman, 2012; Sigelman et al., 1993; Zhu, Liu, & Tardif, 2009), we would expect that informal learning experiences would have equal or greater impact on learning in low SES children based on the success in other domains, such as math (Clements & Sarama, 2007; Ramani & Siegler, 2008; Wilson, Dehaene, Dubois, & Fayol, 2009; Scalise, Daubert, & Ramani, 2018). Further research to address the impact of both formal and informal learning interventions across a diverse population of children is critical.

Promoting disease-prevention strategies in young children is essential for stopping the spread of illness. Again, most interventions with young children still focus on closing schools to eliminate contact among children instead of teaching children to play an active role in reducing transmission. The findings reported here support previous research suggesting that even preschool-aged children can learn causal mechanisms about health and illness, and that knowledge is related to adaptive behavior (Blacker & Lobue, 2016; Conrad et al., 2020; Gripshover & Markman, 2013). Further, it suggests that increasing children's knowledge about illness transmission may not require elaborate and structured interventions at school, and that health practitioners may instead explore informal learning experiences as a more scalable alternative strategy. While parents appear to recognize the importance of discussing illness transmission with their children at home, they are still focused largely on risks and prevention behaviors as opposed to causal mechanisms of transmission. Thus, this work suggests that the design of scalable at home interventions might be effective by teaching parents how to productively discuss illness transmission with their children in a way that promotes healthy habits. This certainly poses a promising new direction for future research.

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Declaration of Competing Interest

The authors report no declarations of interest.

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