

Review

When do children avoid infection risks: Lessons for schools during the COVID-19 pandemic

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SUMMARY

The physical closing of schools because of COVID-19 has disrupted both student learning and family logistics. There is significant pressure for in-person learning to remain open for all children. However, as is expected with outbreaks of novel infections, vaccines and other pharmaceutical therapeutics may not be instantly available. This raises serious public health questions about the risks to children and society at large. The best protective measures for keeping young children in school focus on behaviors that limit transmission. It is therefore critical to understand how we can engage children in age-appropriate ways that will best support their ability to adhere to protocols effectively. Here, we synthesize published studies with new results to investigate the earliest ages at which children form an understanding of infection risk and when they can translate that understanding effectively to protective action.

INTRODUCTION

The ongoing COVID-19 pandemic has highlighted the differential vulnerability of children to outbreaks of novel infectious diseases. Although children are much less likely to suffer severe acute outcomes from COVID-19 infection (Cruz and Zeichner, 2020), that is not always guaranteed to be true for each new disease threat. Although the risks are much lower than for adults during the current pandemic, some children do become seriously ill and can die from COVID-19 infection (Feldstein et al., 2021; Kamidani et al., 2021). Further, already emergent mutated strains of COVID-19 have demonstrated the ability to shift toward causing more severe infection in younger people (de Souza et al., 2021), and until the pandemic is under global control, the emergence of new strains with varied demographic impacts should not be discounted. This is especially worrisome because as more adults and older children are vaccinated, there will be increased evolutionary selective pressure on SARS-CoV-2 to shift to better efficacy of transmission in younger populations (Kennedy and Read, 2020; Saad-Roy et al., 2021). Monitoring, and potentially interrupting transmission dynamics in school-age children is further complicated by our current reliance on either symptoms or known symptomatic contacts for disease surveillance (Lokuge et al., 2021), including how to identify whom to test for new asymptomatic infection. Because children are more likely to be asymptomatic but may still be capable of transmitting infection (DeBiasi and Delaney, 2021), outbreaks among children will be much harder to detect quickly enough to enact effective interventions to keep transmission localized. This leads to a vicious cycle in which relatively benign asymptomatic infections may circulate widely, allowing more evolutionary opportunities for novel mutation that could make the pathogen more successful in younger individuals or even overcoming immune protection among those older individuals who have already been either infected or immunized. Lastly, children continue to be likely to have delayed access to novel interventions such as vaccines or pharmaceutical treatments (e.g., the later approvals during vaccine rollout (Gumbrecht and Fox, 2021; Rodriguez, 2021)).

Of course, the greatest opportunity for transmission of infection among school-aged children is in schools themselves. Because both society and children suffer when schools are closed (Armitage and Nellums, 2020; Esposito and Principi, 2020), there are valid and important reasons to try to keep schools open for in-person learning. This does not mean we should not take every precaution possible to decrease the probability of epidemic spread within and among classrooms for a multitude of reasons. This leaves us with the question of how to keep both children and society most effectively protected while still maintaining in-person learning. While awaiting the rollout of vaccines for younger school-aged children, our best tools have been relying on children's behavioral interventions to limit potential transmission. Indoor social distancing is difficult given the number of children in classrooms, and social distancing alone may not be sufficient

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(Bazant and Bush, 2021). This leaves us predominantly reliant on mask-wearing and hand-hygiene (Liu et al., 2021). Both strategies can be cumbersome and difficult to adhere to for adults (Crane et al., 2021), much less for very young children, leaving us to ask if there are any ways that we can increase adherence and/or efficacy in our youngest populations.

Training in intervention practices at any age can be challenging, but understanding the rationale behind interventions can increase the probability of success beyond simply teaching mechanical procedures (Whitby et al., 2007). Teaching methods used with children should consider children's ability to understand how illnesses spread, and when children can effectively apply their understanding to act appropriately when faced with exposure risks.

Because children's understanding of the world increases with age, we need to answer two critical questions: At what age can children learn to perform protective hygienic practices, and at what age do children understand why engaging in hygienic practices (e.g., how they work, why they are beneficial, etc.) can keep them healthy? Understanding disease transmission, and therefore how some behaviors can protect against it, relies on two separate concepts: direct contagion, in which a person is exposed by contact of some form with an infectious person, and contamination, in which a person is exposed by encountering an area or object harboring infectious agents. Both factors manifest in a variety of complicated and potentially dependent epidemiological mechanisms, and although neither concept is natively apparent, contamination requires the ability to consider intermediate, unobservable states as links in a chain leading to infection risks. Therefore, it is probable that children develop an understanding of direct contagion before they develop an understanding of contamination.

Recent studies have explored the effectiveness of educational interventions to increase knowledge about hygiene and increased hygienic behaviors e.g., (Au et al., 2008; Bieri et al., 2013; Huis et al., 2012; Süß et al., 2011) at particular ages, but to the best of our knowledge, only a handful of recent studies have explored at what age children first develop appropriate understanding they can translate them into self-motivated actions when faced with threats of contagion and/or contamination. Knowing what ages at which children can understand types of exposure risks and then reliably decide to engage in hygienic protective behaviors will allow us to tailor more effective intervention/education strategies as schools remain open. If the youngest children in daycares and schools cannot yet internalize the concepts that govern their own risks or translate understanding of those concepts into behavior, education should avoid focusing on "why" and instead focus on "how," training methods and mechanical skills. However, as soon as children can begin to understand how illnesses are transmitted, education can be shifted to include equal (if not greater) emphasis on the "why", explaining the "how" in terms of the successful interruption of transmission and exploring how insufficient care with the "how" can fail to achieve the goal of the practice. These guidelines could be enacted in group settings and come in the form of advice to parents/caregivers to minimize frustration while increasing the effectiveness of efforts to encourage personal hygienic practices in children.

Here, we review recent empirical studies that investigate the earliest ages at which children form understandings of the risk of infectious diseases and when they can translate that understanding effectively to protective action. These studies were all conducted and/or published before the COVID-19 pandemic, but carry important implications for designing interventions that can help keep our children safe so that schools can remain open during the COVID pandemic as well as in future pandemics.

SYNTHESIS OF WHAT IS KNOWN

When do children learn about illness transmission?

Understanding illness transmission is difficult for young children, as it requires them to reason about hidden or nonobvious properties and mechanisms (Au et al., 1993; Kalish, 1996; Keil et al., 1999; LoBue and Thrasher, 2015). For example, when talking to even the youngest children about illness, we often refer to "germs." But while talking about germs might make the concept of illness transmission somewhat concrete for children, it still refers to a causal mechanism for illness that children cannot see or touch. As a result, it takes some time for children to develop a full understanding of illness transmission (see Figure 1).

Children's reasoning about illness transmission first begins to develop in the preschool years and continues throughout middle childhood (Keil et al., 1999; Myant and Williams, 2005). By the age of 4, children have some understanding of illness transmission and can differentiate between contagious and noncontagious

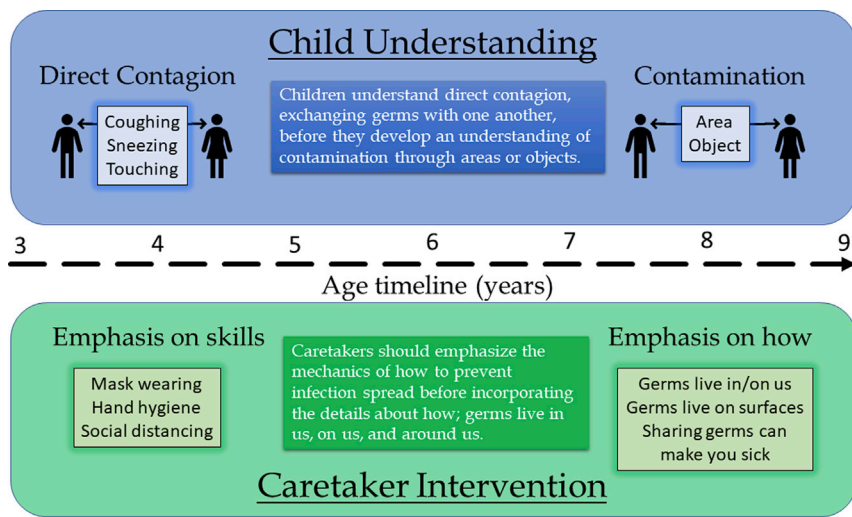


Figure 1. Child understanding and caretaker intervention

Children develop an understanding of direct contagion before an understanding of contamination. As such, caretakers should emphasize the development of skills to prevent transmission before teaching an understanding of how and why disease transmission occurs. Children exhibit considerable variability when they begin to develop a mechanistic understanding of disease transmission. Although there is agreement between the timeline and when age specific behaviors occur, caretakers should allow for variability in children's aptitude in acquiring mechanistic knowledge of disease transmission.

interactions (Kalish, 1996). 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 et al., 2009). Further, using simple forced choice paradigms, preschool-aged children demonstrate some knowledge that "germs" cause illness, and that germs are living or biological entities (Kalish, 1996). At the same age, children also prefer biological explanations for how someone might get sick to social ones (Springer and Ruckel, 1992), demonstrating that they have some basic intuitions about how illness is transmitted.

However, studies examining a wider age-range suggest that a full understanding of illness transmission develops slowly over time and that children's understanding of the complex biological processes that underlie illness transmission do not appear until much later in development (Figure 1). For example, although preschool-aged children can pick out events that they associate with illnesses, they cannot use that knowledge to make predictions about whether someone will become sick after engaging in a risk behavior (Legare et al., 2009). Further, although three-year to 6-year-old children understand that close physical interactions between two people can act as a cue for illness transmission, older (5-year and 6-year-old) children show superior performance when compared to younger (3-year and 4-year-old) children (DeJesus et al., 2021). It is not until the age of seven or even 11 that children's initial intuitions about illness transmission are reorganized into a more sophisticated biological understanding (Myant and Williams, 2008) that supports accurate scientific reasoning. In other words, although children begin to reason about illness transmission at the age of four or 5, they do not typically acquire a full understanding of the mechanisms that underlie illness transmission until several years later (Figure 1).

When do children avoid getting sick?

Although there is a large body of work on what children know about illness transmission, there are only a handful of studies on what children do when faced with the possibility of getting sick. Two recent studies suggest that by the age of six or 7, children can reason about contagion and contamination and behave appropriately when confronted with the risk of infection. DeJesus, Shutts, and Kinzler (DeJesus et al., 2015), for example, probed children's behavior when faced with contamination. They showed three-year to 8-year-old children a video of one actor eating from a bowl of applesauce and a second actor eating applesauce from a second bowl while sneezing into it. Three-year and 4-year-old children were willing to eat the same amount of applesauce from both bowls, but the five-year to 8-year-olds consumed

more applesauce from the clean bowl than from the bowl that had been “contaminated” by the sneeze, suggesting that between the ages of 5 and 8, children begin to avoid contaminated foods. Importantly, however, even though the older children ate more of the clean applesauce than the contaminated applesauce, many of them still ate some of the contaminated applesauce, suggesting that full avoidance may not develop until much later.

In another study, [Blacker and LoBue \(2016\)](#) probed children’s behavior when faced with contagion. In this study, four-year to 7-year-old children were prompted to interact with two confederates—one that was “sick,” and one that was not—and various toys that each of the confederates touched. Children were also given a vignette task to assess their verbal knowledge of contagious illness. Only six-year and 7-year-olds avoided proximity to and contact with the sick confederate and her toys; the four-year and 5-year-olds played equally long with each confederate’s toys and did not avoid physical proximity to either confederate. However, the best predictor of children’s avoidance behavior was not age, but instead, their ability to make predictions about illness outcomes. In other words, even four-year and 5-year-olds avoided proximity to the sick confederate if they had causal knowledge about illness transmission—most of them just did not yet have this understanding.

An additional unpublished follow-up study using a similar methodology measured children’s contact with contaminated objects in the absence of someone who is sick. In this study, four-year and 5-year-old children played with two sets of toys after watching a video in which two confederates played with the same toys. One of the confederates contaminated half of the toys by coughing, sneezing, and wiping her nose while playing with them, whereas the other confederate did not contaminate the remaining toys (method and results in [supplementary materials](#)). Here, children did not avoid contact with the contaminated toys, and children’s knowledge of infectious illness was not predictive of contamination avoidance. Although children did exhibit above-chance performance on the illness knowledge questions, they were unable to apply that knowledge appropriately to avoid contaminated objects. Thus, although preschool-aged children do seem to use their knowledge about illness transmission to avoid people who are sick, their ability to use it to avoid contaminated objects in the absence of a sick person might be more fragile.

Can children learn about illness transmission in a way that translates to behavior?

Altogether, findings from these behavioral studies suggest that children do not spontaneously avoid contact with a contagious person or contaminated foods until the ages of about six or 7. However, they also suggest that causal knowledge about illness transmission might be an important mechanism that leads to these healthy avoidance behaviors. In addition, although most younger children (aged four and 5) do not avoid contagious individuals or contaminated objects, children of this age that happen to have causal knowledge of illness transmission do avoid proximity to a contagious person and they avoid contact with objects she touched. Most children of this young age just have not learned the relevant causal information yet, possibly because they are too young for formal schooling. This opens the question of whether teaching children about illness transmission might lead to the development of healthy behaviors.

[Au et al. \(2008\)](#) provide evidence that knowledge-based interventions can indeed be effective in producing health-related behaviors if they present causal information about illness transmission, at least in older children. They used an intervention with children aged eight and older called “Think Biology”, that teaches children about the biological properties of germs. Children in this intervention showed an increase in their causal knowledge of how illness is transmitted along with an increase in hand washing behavior before handling food even though they were never taught about that behavior specifically in the intervention. They outperformed children in control knowledge-based interventions that taught children a list of risk behaviors to avoid and preventative measures to engage in. Despite being specifically told about hand washing, children in this control condition did not show an increase in causal knowledge or hand washing behavior. Thus, it appears that knowledge interventions that improve children’s causal knowledge support adaptive behavioral change. However, it is currently unclear whether such interventions would lead to conceptual and behavioral change in children younger than age 8.

Only one recently published pilot study tested whether younger, preschool-aged children (aged three to 5) can learn a simple causal explanation about illness transmission, and whether learning would affect their behavior ([Conrad et al., 2020](#)). In the study, researchers first assessed preschoolers’ baseline knowledge

about illness transmission. A week later, the same children were presented with an excerpt from a storybook about a little girl who got sick after interacting with a friend. After the book reading, children were given the same knowledge assessment again, along with a behavioral assessment of contamination avoidance, where they were offered one of two toys that had either belonged to a child who had a cold (contaminated) or a toothache (uncontaminated). Children who received contagion-relevant explanations for illness transmission in the book showed significant improvement in their knowledge about illness transmission from pretest to posttest, whereas children who did not receive causal information about transmission (or no book at all) did not a significant improvement. Most importantly, children who provided these accurate, contagion-relevant explanations at posttest were more likely to avoid a contaminated toy than children who did not accurately provide these explanations (Conrad et al., 2020). Although these results come from just a single pilot study, they raise the possibility that children as young as four and five can learn about illness transmission in a way that affects their behavior.

One implication for this work is that informal interventions—such as a simple storybook reading—might be an easy way to teach children about the mechanisms underlying illness transmission at an early age. In fact, simply recommending that parents begin to have discussions with children about illness transmission at home might be useful. Recently researchers (Leotti et al., 2021) polled 143 families with young children after the onset of the COVID-19 pandemic and found that almost all parents (96%) were talking to their children about illness transmission. On top of that, the researchers compared preschool-aged children's knowledge about illness transmission and contamination avoidance in two samples—one tested during the first 6 months of the COVID-19 pandemic in the United States, and one tested immediately prior. Children tested during the pandemic demonstrated greater explicit declarative knowledge and causal reasoning ability about contagion than did children tested immediately before the pandemic, especially in the domain of proximity (likely because of increased talk about social distancing). Further, explicit declarative knowledge about illness transmission and causal knowledge about the role of proximity predicted children's avoidance behavior (Leotti et al., 2021).

IMPLICATIONS OF WHAT IS KNOWN FOR DESIGNING INTERVENTIONS: ON KEEPING SCHOOLS OPEN

As the past two years have made painfully clear, keeping schools open for in-person instruction is one of the most important goals in returning societal function to normalcy. However, normalcy can only be achieved with sufficient guarantee of everyone's personal safety in the face of ongoing circulation of COVID-19, including whatever novel strains may arise. Non-pharmaceutical interventions are likely to remain the best means of protecting children under the age of 12 well into the academic year, and therefore also the best means to protect against schools becoming reservoirs of transmission that continue to expose those who have not been, cannot be, or do not mount sufficient immune response to be protected by having been vaccinated. Although only a handful of studies have focused on when children can develop understanding of illness transmission and translate that understanding into effective, protective action, the evidence is promising and there are recommendations we can make to concerned parents and actions we can take in our schools themselves as classrooms strive to remain open.

The results of the study discussed above that examined illness knowledge before and after the onset of the COVID-19 pandemic suggests that casual conversations about illness transmission at home might promote health-related behaviors in children (Leotti et al., 2021). However, it is important to note that although 59% of parents who were polled in this study reported that their children had a strong understanding of how to avoid illness (e.g., washing hands, avoiding contamination), only 5% of them believed their child would behave in ways that would keep them from exposure. This disconnect might be because parents' reports of discussions with their children center around risk prevention strategies (71%) rather than causal mechanisms of illness transmission (21%). This suggests that parents might not know how to engage their children in productive conversations about illness transmission, and thus highlights the potential need to disseminate informational guides to parents about how to talk to their children about illness most productively (Leotti et al., 2021). Of course, it may also be that because of responsible concern about their children's safety, parents are more likely to remember instances of failure to follow behavioral guidelines rather than average but imperfect attempts. From an individual perspective, this is of course important, but from a public health perspective, reduction in the frequency of failure in hygienic behavior can still meaningfully improve overall societal outcomes and should still be encouraged.

Although parents are natural partners in the effort to keep their children safe, these results also suggest that teachers, caretakers, and those who communicate regularly with children can and should consider incorporating “why-based” conversations about disease intervention and health into their lesson plans in preparation throughout the school year. It is of immediate and critical importance to understand how to educate young children in ways that best enable and empower them to protect themselves and others without either alarming or overburdening them. Designing educational conversations in age-appropriate ways may be one of our most effective tools for trying to mitigate individual and societal risks as in-person instruction continues this fall and next spring. However, questions remain, as the literature on children’s behavioral responses to illness risks is still relatively small in the psychological literature. For example, we still don’t know whether children are motivated to comply with social distancing and masking guidance given the seriousness of COVID compared to other common illnesses or how these behaviors might be moderated by their families’ beliefs (e.g., political orientation). Further, we don’t know how the long incubation period for some illnesses and the fact that some individuals do not experience severe symptoms affects children’s reasoning or health-related behaviors. These and many other unknowns suggest that interdisciplinary research on children’s health-related behaviors and the efficacy of knowledge-based behavioral interventions are still greatly needed.

Although our discussions throughout this paper have naturally focused on the ongoing risks from COVID-19, the implications of these findings are broader than the current pandemic. Already, epidemiologists have begun to discuss how diseases ranging from influenza to those usually prevented by the standard childhood vaccine schedules may exhibit unusual and problematic patterns because of the fallout from COVID-19 disruptions. Improving educational tools that effectively support health protective behaviors will help our children improve their own safety not only during this current health threat but against whatever is just around the corner.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at <https://doi.org/10.1016/j.isci.2022.103989>.

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AUTHOR CONTRIBUTIONS

N.H.F. and V.L. drafted the manuscript. K.A.B. collected and analyzed the data. C.A.P. assisted and provided feedback on all aspects of the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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