Do you see what I see? Children's understanding of perception and physical interaction over
video chat

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Data availability statement

The data that support the findings of this study are openly available on the Open Science Framework at https://osf.io/jz9vt/?view_only=2e39347b50214aeb86da18a1aea0a7c1.

Abstract

In 2020, millions of children shifted to using video chat for core aspects of education and social interaction. While video chat allows for genuine social interaction – in which the partner can see and hear you – affordances in other modalities are limited (e.g. touch). Do children understand the nuanced affordances and limitations of video chat? Here we provide evidence of these abilities at preschool age. Prior to COVID-19, we conducted an experiment with 4-year-old children (N=44). Each child was introduced to people over video chat, in person, and in a photograph. Children judged whether each person could see, hear, feel, and physically interact with them. We found that children made nuanced judgements about the affordances of video chat, judging that a person over video chat can see, but cannot feel a touch nor physically interact through the screen. Children's answers about hearing were divided, with children answering that the person over video chat could hear more often than for a photograph, but less often than for in-person interaction. Overall, by age four, children understand that video chat has a mixture of life-like affordances and picture-like limitations, showing the presence of a necessary cognitive prerequisite to effective use of video chat in early education.

Keywords: technology; video chat; cognitive development; theory of mind; representation

Introduction

In 2020, millions of children suddenly shifted to using video chat for core aspects of education and social interaction (Neil et al., 2020; Singer & Brodzinsky, 2020). This shift magnified a pre-existing trend toward regular use of video chat in early childhood (McClure & Barr, 2016). Video chat serves to maintain relationships between young children and remote grandparents, as well as parents separated by divorce, military deployment, or incarceration (Ames et al., 2010; Forghani & Neustaedter, 2014; McClure et al., 2015; Madianou & Miller, 2012; Yarosh et al., 2009, 2011).

Children treat people on video chat as social partners from early in life (Tarasuik, Galligan & Kaufman, 2011; 2013), but do children understand the unique nature of video chat? Video chat is both a representation, or symbol – of something not actually there – and a live, in-person social interaction (Troseth, 2010; Roseberry et al., 2014). As a result, video chat contains a mixture of life-like affordances and novel limitations: While video chat allows the partner to see and hear you, touch and physical interaction are not possible. Given the central role of video chat in the lives of young children, and its unique nature, it is important to investigate how children conceive of and understand social interactions over video chat.

Children's understanding of representational media

Representations, such as pictures or television images, symbolize something that is not actually there (DeLoache, 2002; Gibson, 1979). Learning to treat an image as a representation is cognitively challenging for children: It involves conceptualizing an image both as a physical object (e.g. the screen) and also as a depiction of something else, a capacity termed dual representation (DeLoache, 2002). Without this understanding, children may treat television

images as real (the “magic window” hypothesis, Hawkins, 1977), or ignore information from video as unrelated to reality (the “video deficit”, Anderson & Pempek, 2005).

Toddlers and young preschool children make errors that hint at specific challenges with the duality of representations. At age 3, many children answer that a picture or video of a cup would spill if the image were turned upside-down (Flavell et al., 1990); at age 2, children have been observed to retrieve real-life objects to resolve problems on-screen (e.g. paper towels after seeing an egg break on television, Jaglom and Gardner, 1981; Troseth, 2010). At younger ages, nine-month-old infants interact with photographs and television images by attempting to grasp them, thus treating images as though they had the physical affordances of real objects (DeLoache et al., 1998; Pierroutsakos and Troseth, 2003). These errors occur in spite of infants’ and young children’s ability to tell apart images from their referents (Diener et al., 2008; DeLoache et al., 1998), and also to recognize their similarity (DeLoache et al., 1979; Preissler & Carey, 2004; Shinskey & Jachens, 2014).

Children also show a systematic tendency to ignore information from video. This tendency, termed the “video deficit”, takes the form of a transfer deficit in children’s learning from video versus in-person events (Anderson & Pempek, 2005; Barr & Hayne, 1999; Diener et al., 2008; Kuhl et al., 2003; Reiser et al., 1984; Roseberry et al., 2009). The representational nature of video contributes to this transfer deficit: Simply convincing two-year-old children that a television screen is actually a window, thereby removing its representational quality, is enough to cause a greater number of children to use information from the video to find a hidden object (Troseth & DeLoache, 1998; Troseth, 2010).

The representational nature of pictures and video also has implications for children’s reasoning about others’ mental states, such as others’ knowledge. Children’s typical strategies

for determining another person's knowledge include following the direction of their gaze, noting opaque physical obstacles blocking their view, and understanding that seeing leads to knowing (Brooks & Meltzoff, 2002; Pillow, 1989). When viewing a person in a photograph or pre-recorded video, these strategies are not relevant for reasoning about visual access, and may be actively misleading. Instead, children face the challenge of overriding their typical strategies for reasoning about what others can see, and shifting to a distinct understanding that these rules do not apply through the screen.

When considering pre-recorded video, children appear to meet this challenge by four years of age. To determine whether young children understand that people on television lack perceptual access through the screen, Flavell and colleagues (1990) compared 3- and 4-year old children's reasoning about a person on television, to a person in a photograph or present in the room (conditions which were used as baselines for comparison). Children were asked whether each person could see, hear, and know about the actions of the experimenter in the room. Four-year-old children (but not three-year-old children) answered in an adult-like way, judging that a person in a pre-recorded video could not see, hear, or know about the actions of the experimenter. By four years of age, children were thus able to override their typical strategies of using gaze direction to imply perceptual access when considering pre-recorded video. Instead, children appeared to categorize pre-recorded video as similar to photographic representations in terms of the lack of perceptual affordances, and to clearly distinguish pre-recorded video from an in-person interaction (Flavell et al., 1990).

Children's concept of video chat

Video chat has much in common with pre-recorded video – it takes the form of a two-dimensional image on a screen, with a display that is often smaller than life-size. However, video chat contains an additional form of duality: The person on the screen is at once socially ‘present’ in the room, yet also physically in another location. In other words, video chat is simultaneously a representation, and also a real, responsive social interaction (Roseberry et al., 2014; Troseth et al., 2006). Do children have a distinct understanding of video chat, which contrasts with their understanding of live interaction and of purely representational stimuli?

One possibility is that young children may be limited to categorizing a stimulus either as fully representational, or fully present and real. In particular, existing data is consistent with the idea that children may treat video chat as equivalent to in-person interaction. From early in childhood, a video chat connection with a parent has much the same impact as in-person presence: Children aged 1 to 5 years were content and played for longer when left alone with a parent on video chat, versus when left alone, or when left with only an audio connection to their parent (Tarasuik, Galligan & Kaufman, 2011; Tarasuik, Galligan & Kaufman, 2013). Children also showed similar levels of interactivity with their parent over video chat as during in-person interaction (Tarasuik et al., 2011). Compared to pre-recorded video, children show more exact imitation of a person over video chat (Nielsen, Simcock & Jenkins, 2008). Children also recognize and prefer people they have interacted with over video chat, more so than people in matched pre-recorded videos (Myers et al., 2017).

These data are consistent with a modern form of the magic window hypothesis (Hawkins, 1977): If young children equate video chat with in-person interaction, children may consider people over video chat to be actually present, and fully and physically real. This “modern magic window hypothesis” would also help explain the robust finding that video chat overcomes the

learning deficit from video (Troseth et al., 2006; Myers et al., 2017; Roseberry et al., 2014).

Children could avoid the typical video deficit by not considering video chat to be video at all, thereby treating the image as a person rather than a symbol.

If children equate video chat with in-person interaction, then they should make specific, predictable errors. In particular, children should over-estimate the capacities of people over video chat: While video chat allows the partner to see and hear you, it does not allow for touch or physical interaction. By this account, children should fail to recognize these limitations.

Alternatively, children may have a specific concept of what people over video chat can do, distinct both from their understanding of pure representations (e.g. photographs), and real in-person interactions. This would show that children can flexibly form a new category that bridges these two ontological kinds. However, children's understanding of the perceptual affordances and limitations of video chat has not yet been directly tested.

Here we aim to characterize 4-year-old children's understanding of the affordances and limitations of video chat, asking whether children have a distinct understanding of video chat which contrasts with their understanding of live interaction and of purely representational stimuli. To test this, using a within-subject design, children were introduced to three unique people in three ways: over video-chat, in-person, and in a photograph. For each person, children were asked to judge the person's capacity to see, hear, feel a touch, and physically interact with an object in the room. As in previous work (Flavell et al., 1990), the photograph and in-person conditions served as baselines for comparison, allowing us to ask whether children's judgments about video chat resemble or differ from their responses regarding a real person and a representation of a person, for each perceptual or physical modality.

We expected that most children in our sample would have prior experience with video chat (which we verified with a parent questionnaire). Our intention in the experiment was to examine children's existing conception of video chat, based on their prior experience – not to allow children to learn about the medium from experience during the task. We therefore aimed to avoid providing evidence from the researchers' behavior about whether they could or could not perceive the stimuli. To keep this ambiguous, researchers who were the target of questioning remained (unnaturally) unresponsive throughout the task. To explain their unresponsive behavior, children were instructed that there was a rule in the game: 'The other people have to sit there quietly no matter what happens, so that they can't give away the answers'. In this way, the task aimed to examine children's existing concepts of video chat, without giving direct evidence of the partners' capacities during the interaction.

In addition to these primary measures, we asked several exploratory questions with the aim of further characterizing children's understanding of video chat. These questions probed children's thinking about the location and size of the person shown on the screen (e.g. if we look behind the iPad, will she be there?), as well as their understanding of the device itself (if we open up the iPad, what would we find inside?). Lastly, we coded whether children looked at the self-view (a small picture-in-picture window, shown in the corner of the screen) after being asked what their video chat partner could see. In typical in-person interaction, inferring what others can see presents a cognitively challenging theory of mind problem, as we lack direct access to another's point of view (e.g. Hamilton, Brindley & Frith, 2009). Video chat provides children with a new potential strategy for perspective taking: If children can learn to reference the self-view, they would gain unique, direct access into what the other person can see (given that they are looking at the screen). We hypothesized that if children understand the novel affordances of

video chat, children may also look at the self-view to gather information about their partner's visual access. All data are available on OSF at

https://osf.io/jz9vt/?view_only=2e39347b50214aeb86da18a1aea0a7c1.

Method

Participants

N=44 4-year-old children participated (21 male, 23 female; Mean age=4 years, 5.7 months; SD=3.8 months; Range 4;0 to 5;0 years). Children were from the San Diego metro area, and were recruited via email and phone call invitations from a database of local interested families. An additional 4 children were tested but excluded for reasons determined a-priori: Extreme distraction and inattention (1); and technical difficulties (3). The original intended sample size was N=48; data collection was concluded without the final four participants due to interruption from COVID-19 in mid-March of 2020.

Design

Each participant completed 12 trials for a within-subject design, with one trial for each of four modalities (whether another person could see, hear, feel or physically interact), across three presentation types (when the person was presented in person, in a photo, or over video chat).

Questions were blocked by presentation type, with the order of blocks counterbalanced across participants. Question orders within each block were counterbalanced across participants using a Latin square design. Conducting the experiment involved three researchers: A primary experimenter, who interviewed the child; a researcher who appeared during the in-person trials;

and a researcher who appeared over video chat during the video chat trials. Which researcher served each of these three roles was counterbalanced across participants.

Procedure and Stimuli

All testing took place in a child-friendly testing room in the lab, with the participant seated opposite the primary experimenter across a child-size table. All data were collected prior the onset of stay at home orders due to COVID-19.

Two warm-up questions familiarized the participant with the situation and format of test questions, via a brief experience with a photograph and a real-world physical object (as in Flavell et al., 1990). Children were shown a clear glass partially filled with water, and asked: “When I turn this glass upside down, what will happen: Do you think the water will spill out? Or will the water stay in the glass?”. After the child’s answer, the experimenter turned the glass upside down over a bowl, and provided verbal feedback (“the water spilled out”). Second, children were shown a laminated photo of a glass of milk, and asked the same question regarding “turning the picture of a glass of milk upside down”. After the child’s answer, the experimenter turned the picture upside down and again provided verbal feedback (“the milk stayed in the glass”).

Children then completed three blocks of four test trials, one block for each presentation type (in-person, photo, video chat). At the start of each block, a new person was introduced. Each person was a different female individual, none of whom had interacted with the participant prior to their role in the procedure.

The introduction of people in-person, in a photo, and over video chat was closely matched, with the introduction of “my friend [Name]” (In-person, Video chat), or “a picture of my friend [Name]” (Photo). For the in-person trials, a person entered the room and sat at the

table. For the video chat trials, a person was called by the experimenter using FaceTime on an iPad, and the iPad was placed on a bookstand at the same location at the table. For the photo trials, a laminated photo of a person was placed on the same bookstand at the same location at the table. For the in-person and video chat trials, there was a single verbal exchange with the experimenter when the person first appeared (“Look, it’s [Name]!”; “Hi everyone!”). After this, the in-person and video chat researchers maintained a neutral-positive facial expression with forward gaze direction, did not respond to speech or other stimuli, and produced minimal body movement (with some small movements to prevent appearing unnaturally still). To prevent children from interpreting this unresponsive behavior as indicating a lack of perception, children were told that there was an important rule in the game: that the other person “has to sit there quietly, no matter what happens, so that she can’t give away the answers.”

On each test trial, the experimenter showed a stimulus, and asked a question of the format: “Does [Name] [see, hear, etc.] [the stimulus], or does she *not* [see, hear, etc.] it?” Question wording for each modality was identical across all presentation types (in-person, photo, video chat).

Visual Modality

Visual stimuli were three different stuffed animals of the same size (monkey, alligator, rhinoceros), placed on the center of the table, within direct line of sight of the child and the other person/photo. Children were first asked to identify the kind of animal it was, and were then asked: “Does [Name] see the stuffed animal? Or does she *not* see it?”

Auditory Modality

Sound stimuli were hand bells, rung briefly by the experimenter (~3 seconds); across the three blocks the hand bells varied in color (red, yellow, blue) and acoustic pitch, and were

otherwise identical. Children were first asked to identify the color of the bell, after which the bell was rung and children were asked: “Does [Name] hear the sound of the bell? Or does she *not* hear it?”

Tactile Modality

Tactile stimuli involved the experimenter poking the other person's arm with an index finger; poking the same body location in the photo; or poking the same body location on the iPad screen. Children were asked: “Does [Name] feel me poking her? Or does she *not* feel it?”

Physical Interaction Modality

Children were shown a hair tie (colored grey, blue, pink across trials). Children were first asked to identify its color, and then asked: “Can I use this hair tie to put [Name's] hair in a ponytail? Or can I *not* use it to put her hair in a ponytail?” All experimenters had long hair, worn down, to make this possible for all individuals if they had been present in-person.

Additional Measures

Exploratory Questions

At the end of the session, several exploratory questions were asked, with the aim of further characterizing children's understanding of video chat. In the following fixed order, these questions were: “If we look behind the iPad, will [Name] be there? Or will she not be there?”; “If we open up the iPad what would we find inside? Would we find [Name], wires, or something else?”. If the child responded that they expected to find the person inside, they were asked: “If she came out of this iPad, how big would she be? Would she be this big? [show height of iPad] Or, would she be as big as me?”. If the child responded “something else”, they were asked what they expected to find inside.

Figure 1: Method. In a within-subject design, children were introduced to a person in each of three presentation types (in-person, in a photograph, and over video chat), and asked about the person's capacity to see an object, hear a bell, feel a touch, and physically interact with an object in the room. On each test trial, the experimenter showed a stimulus, and asked a question of the format: "Does [Name] [see, hear, etc.] [the stimulus], or does she *not* [see, hear, etc.] it?"

Looking at the Self-View

To determine whether children looked at the self-view to gather information about what their video chat partner could see, we coded whether children looked at the self-view (a small picture-in-picture window, shown in the corner of the screen), or not, after being asked what their video chat partner could see. This was coded by the primary experimenter during the testing

sessions. Any look at the viewfinder was coded from the point in time when the word “see” was spoken during the question (“Does X see...”), until the time when the children had finished their verbal reply. The primary experimenter sat approximately 36 inches directly in front of the participant, able to see their face and eye gaze direction (see Fig. 1).¹

Parent Questionnaire

To determine whether children had prior experience with video chat, we asked parents/guardians to fill out a brief survey with the following questions: “Has your child ever participated in a video chat call before?” (Yes/No/Unsure); “At what age did your child first begin using video chat?” (Free response); “How frequently does your child participate in video chat?” (Multiple choice, 7-point scale, from very rarely to multiple times a day); and “How long does an average video call last (in minutes)?” (Free response). The parent questionnaire was added after data collection began, and was given to the final 30 of 44 families in the sample, all of whom completed the questionnaire.

Results

To ask whether participants’ responses changed based on presentation type and modality, we used logistic regression to predict participants’ responses (yes/no) with the predictors of presentation type (in person, photo, video chat), modality (vision, audition, tactile sensation,

¹ Using recorded videos of the sessions, we also aimed to determine whether children looked at the self-view when asked what their partner can hear, as a control condition. However, we ultimately determined that recorded videos of the sessions did not allow for reliable coding of looking behavior: Once the child turned to look at the iPad, their face was no longer in view (see camera perspective in Fig. 1). As such, the written comments of two off-line coders expressed uncertainty, and we found low reliability between coding performed live during the session, and coding performed from the recorded videos of the sessions (23% agreement). We therefore interpret data regarding the self-view with caution (see Discussion).

physical interaction), the interaction of these two factors, and subject (as a random factor). There was a significant interaction between presentation type and modality (nested model comparison, $\chi^2(6) = 19.07, p = 0.004$). There were also significant main effects of presentation type and modality: Contrasting with video chat as the reference level, in-person differed, $\beta = 3.00, p < 0.0001$; photo did not, $\beta = 0.18, p = 0.77$. With physical interaction as the reference level, vision differed, $\beta = 3.43, p < 0.0001$; audition, $\beta = 1.02, p = 0.08$, and tactile, $\beta = -1.23, p = 0.06$ showed nonsignificant trends. Follow-up analyses then examined each modality separately, to further characterize how children's judgments about video chat differed from the two baseline conditions (in-person, photograph).

Vision by the video chat partner

Most children judged a person capable of seeing an object over video chat (79.5% of participants, see Figure 2), and there was no difference between children's judgments about capacity to see over video chat vs. in-person interaction (both were 79.5%; $p = 1.0$; logistic regression, comparing in-person to video chat as the reference level). In contrast, children accurately judged a photo capable of vision less often (50.0% vs. 79.5%; $\beta = -2.42, p = 0.0018$).

Audition by the video chat partner

Only 50.0% of participants judged the video chat partner capable of hearing. However, they accurately judged the photograph of a person capable of hearing less often (27.3% vs. 50.0%, $\beta = -1.53, p = 0.013$), and the in-person partner capable of hearing more often (79.5% vs. 50.0%, $\beta = 2.08, p = 0.002$), suggesting that children distinguish hearing in video chat from hearing in in-person interaction and photographs.

Figure 2: Results. Four-year-old children's judgements of the affordances and limitations of a person over video chat, as compared to the same judgments of a person present in-person, and a person in a photograph. Y-axis shows proportion of children answering "yes". X-axis shows the type of question asked, regarding both modality (e.g. vision) and presentation type (e.g. in-person). Error bars are standard error.

Tactile sensation by the video chat partner

Most children judged that a person over video chat could not feel touch through the screen (77.3% no; 22.7% yes), and there was no difference between children's judgments about video chat vs. a photograph (22.7% vs. 18.2%, $\beta = -1.17$, $p = 0.33$). In contrast, children accurately judged a person capable of feeling touch more often when they were present in-person than over video chat (63.6% vs 22.7%, $\beta = 10.27$, $p = 0.0002$).

Physical interaction with the video chat partner

Most children judged that they could not physically interact with a person over video chat through the screen (63.6% no; 36.4% yes), and there was no difference between children's judgments regarding physical interaction for the photo vs. video chat (38.6% vs 36.4%, $\beta=0.2$, $p=0.75$). Participants accurately judged physical interaction more possible for in-person interaction than over video chat (75.0% vs 36.4%, $\beta=3.57$, $p=0.0004$).

Exploratory questions

When asked whether the person on-screen would be behind the iPad, 40 of 44 children answered that no, she would not be there ($p<0.0001$, binomial test vs. 0.5; the remaining 4 of 40 answered yes). When asked what was inside the iPad, 12 of 44 chose 'wires', 8 chose the person on-screen, and 2 did not answer. The remaining 22 chose something else, further specifying 'nothing' (8/22), descriptions of people or objects in the room (6/22), that they did not know (3/22), or miscellaneous other answers (e.g. 'black stuff', 5/22). Children who expected to find the person on-screen inside the iPad were asked how big she would be, if she came out; most answered she would be as big as an in-person adult (7/8), not the size of the iPad (1/8).

Looking at the self-view

When asked about what the video chat partner could see, 86% of participants looked at the self-view on the iPad's screen (37/43 participants; looking data missing from one participant due to experimenter error). While justifications were not prompted, one participant spontaneously verbalized their strategy for knowing what their partner could see, explaining that "she does" see it, then pointing to the self-view and stating "because it's on the screen".

Parent questionnaire

The majority of children in our sample had prior experience with video chat. Only one child had not participated in a video chat call before the experiment, of the 30/44 children with parent questionnaire data. Two other parents were unsure if their child had used video chat, and the remaining 90% of children had participated in a video chat call before (27 of 30 participants with parent questionnaire data). This experience started early: 33.3% of children used video chat by or before 6 months of age, and 83.3% by or before a year of age or 'in infancy' (25 of 30). An additional 13.3% of children used video chat by two years of age (4 of 30). Children's video chat calls occurred with a modal frequency of about once a week (11 of 30, 4 on the 7-point scale; $M=3.63$, $SD=1.65$) and a range from very rarely to almost every day (1-6 on the 7-point scale). The modal length of typical video chat calls was 11-20 minutes (9 of 30), with the majority of participants reporting typical call lengths of 20 minutes or less (24 of 30).

Discussion

Video chat is simultaneously a representation of someone not physically present, and also a real social interaction (Roseberry et al., 2014; Troseth et al., 2006). From early in childhood, children treat a person over video chat as a social partner (Nielsen et al., 2008; Myers et al., 2017), and in many ways treat video chat as equivalent to in-person interaction (Tarasuik, Galligan & Kaufman, 2011; Tarasuik, Galligan & Kaufman, 2013). This raises the possibility that young children could equate video chat with in-person interaction, by considering people over video chat to be actually present, and fully and physically real.

Our data show that by four years of age, this is not the case: Children were able to distinguish between the capacities of people over video chat versus live in-person, and understand the unique ways that video chat limits perception and physical interaction. In particular, children accurately judged that a person over video chat cannot feel touch, nor physically interact, through the screen. For these modalities, children's thinking regarding the affordances of video chat dramatically differed from their thinking about in-person interaction, and more closely mirrored their answers about a photograph of a person – a purely representational stimulus. In contrast, children judged that a person over video chat can see objects through the device, making comparable judgements for video chat as for someone present in-person. Children's answers for the auditory modality were divided: Children more frequently judged that a person over video chat could hear than a person in a photograph, but less frequently than for someone present in the room.

Overall, at four years of age, children had a nuanced understanding of perception and interaction over video chat, and their concept of what people could do and perceive over video chat differed from their expectations regarding both live interaction, and purely representational stimuli. In effect, this shows flexible reasoning about video chat as a new type of stimulus that has qualities of both representations and in-person interactions. This understanding provides a foundation for effective use of video chat by children in early education and social interaction.

When learning from video chat, children do not show the typical deficit in learning from video (Troseth et al., 2006; Myers et al., 2017; Roseberry et al., 2014). If children considered video chat as similar to in-person interaction in all respects, this would have provided a plausible explanation for this pattern of findings – i.e, that children do not consider video chat to be video at all. In contrast, we find that children make explicit distinctions between the capacities of a

person over video chat versus present in-person, falsifying this idea. Thus, current data are consistent with existing explanations for the potency of video chat in learning, which emphasize the crucial role of social contingency (Troseth et al., 2006; Myers et al., 2017; Roseberry et al., 2014).

Explaining variation in children's answers

While these patterns of responding were robust, not all children gave the expected answers. Even when judging whether a person present in the room could see or hear something in front of them, only 80% of children answered affirmatively. Conversely, when asked whether a person in a photograph could see an object in front of the photograph, children answered yes less frequently (a reduction of almost 30%) – but still, 50% of children answered that the person in the photograph could see the object. What accounts for variation in children's answers?

The experimenters' unresponsive behavior likely accounts for some aspects of this variation. To avoid providing direct evidence of whether they could or could not perceive the stimuli, experimenters remained intentionally unresponsive, apart from one initial, non-specific verbal greeting. Children were instructed that this unresponsiveness was due to 'the rules of the game' (and as such should be disregarded). However, some children may still have taken the experimenters' unresponsiveness as evidence of lack of perceptual ability. This may have led to reduced certainty that the video chat partner could indeed see and hear them. An alternative approach involving more extensive, naturalistic interaction would likely increase children's certainty that the video chat partner could see and hear them.

Two other factors may explain why many children answered that a photograph could see or interact with them. In part, this may be due to children's well-established bias toward

affirmative answers (the 'yes' bias, Heather Fritzley et al., 2013; Okanda & Itakura, 2010). In addition, this may be due to the pragmatics of language about symbolic stimuli: It is difficult to unambiguously refer to a photograph as an object in its own right, rather than as a symbol of the photograph's referent (the person herself, as if present). Children expect words to refer to objects, not to pictures themselves (Preissler & Carey, 2004). Thus, when asked whether the person in the picture sees the object, some children may have interpreted the question as referring to the capacity of the real person pictured in the photograph, if she had been present, rather than the image itself.

Differences by modality: The case of audition

Our data also raise questions about how children reason about hearing over video chat. Children's answers for this modality were divided: Although children more frequently judged that a person over video chat could hear than a person in a photograph, only approximately half of children judged that the person over video chat could hear through the screen. We see two possible interpretations of this finding.

First, it may be more difficult for children to reason about what another person can hear, versus what another person can see or feel. Several studies have found that children have a more difficult time understanding how hearing leads to knowing, versus how seeing leads to knowing (O'Neill & Gopnik, 1991; Pillow, 1993, Weinberger & Bushnell, 1994), although findings are mixed (Schmidt & Pyers, 2014). In addition, children have greater difficulty understanding audio-only connections (i.e. telephone calls) than video connections (Ames et al., 2010; Ballagas et al., 2009; Tarasuik et al., 2013). Greater difficulty reasoning about auditory access or audio

communication may explain children's greater uncertainty about the auditory modality in video chat.

Alternatively, children's uncertainty about auditory access may reflect a rational, adult-like inference, for two reasons. First, with the exception of one initial verbal greeting, the video chat partner in our experiment never spoke or responded to sound. Therefore, children may have reasonably been uncertain about whether this person could hear them. Second, children's uncertainty could also reflect an accurate understanding of the many ways that video chat audio can be disrupted: The mute button may be activated; the volume on the other device may be turned down; or there may be a problem with the microphone or audio connection. Technological problems with the auditory connection are not immediately obvious, and must instead be inferred based on whether the other person responds to sounds – evidence which was not made available in our study, as the experimenter remained intentionally unresponsive. In contrast, in the visual modality, if the call's connection is severed this interruption is typically apparent on the screen. Thus, it is possible that children's uncertainty about hearing in video chat reflects a rational, adult-like inference. Without contingent auditory interaction, there is in fact greater uncertainty about whether the person over video chat can hear.

Use of the self-view in perspective taking

When interacting over video chat, children have access to a unique source of information about the other person's perspective: The self-view, a frame on-screen which displays the visual scene *as the other person sees it* on their screen. Our dataset raises questions regarding unique ways that the self-view may give children new insight into others' perspectives.

The development of perspective taking is of broad interest to scholars interested in theory of mind and social cognitive development: Because we lack direct access to another person's point of view, other's visual perspectives must be inferred. Perspective-taking is cognitively challenging, particularly for young children and for people with Autism Spectrum Disorder (Birch et al., 2017; Hamilton et al., 2009; Newcombe & Huttenlocher, 1992; Piaget et al., 1967).

The video chat interface simplifies the problem of perspective-taking, potentially scaffolding mental state reasoning by providing a direct representation of the other person's visual perspective. Children in our dataset appeared to make use of this feature: Just after the vision question was asked, the majority of children leaned over to look at the self-view on the device's screen, as if to check whether the object in question was within view. There are, however, limitations to our data on this issue: In particular, due to a lack of data on children's looking behavior on other (non-sight) trials, we cannot rule out the possibility that children looked at the self-view after any question, not only the sight question. Anecdotal evidence suggests that at least some four-year-old children understand the self-view as specifically containing information about visual perspective. As one participant spontaneously explained: "she [the experimenter] does [see it], because [points to self-view] it's on the screen". Future work should compare children's rate of looking at the self-view when reasoning about what their partner can see, to their behavior when reasoning about other capacities of their partner. If children reference the self-view specifically to learn about their partner's visual access, then they should look at the self-view more frequently when reasoning about vision than about other capacities.

How do children learn about the affordances of video chat?

How do children learn about the perceptual affordances and limitations of video chat? Anecdotal reports suggest that unlike 4-year-olds, toddlers may misunderstand the nature of video chat, overestimating the extent to which the person is really present (e.g. putting raisins behind an iPad for grandpa to eat later; LaFrance, 2015). The nature of children's errors, and the age at which they make them, may inform our understanding of the developmental processes by which children come to understand video chat. Here we present a hypothesis regarding how this understanding may develop, at ages prior to (or experience levels lower than) those of the children in our sample.

Video chat crucially differs from pre-recorded video in allowing for social contingency. Here, social contingency refers to conversational turn-taking: Iterated back-and-forth responses, with complementary rather than identical content, which are relevant and appropriate for the social context (Csibra, 2010, Roseberry et al., 2014; Troseth et al., 2006). This definition goes beyond but includes the traditional sense of contingency in terms of timing and reliability (Beebe et al., 2011; Catmur, 2011).

The social contingency present in video chat may have dramatic implications for children's conception of video chat: It may provide children with conclusive evidence that their video chat partner can see and hear them. This evidence may change children's conception of what a person on video can do. For infants, simply observing a blob-like object producing sounds timed contingently on the infants' own behavior is sufficient to lead infants to treat the object as capable of sight, and subsequently follow its gaze (Johnson, Slaughter & Carey, 1998; Johnson, 2003). In a similar manner, experience with contingent interaction over video chat may allow children to conclude that people on video chat can see and hear them. This inference may

explain why contingency leads children to view a person on video chat as a social partner (Nielsen et al., 2008; Myers et al., 2017; Tarasuik et al., 2011).

Existing data shows that experience with a live video of themselves can change the way children think about the nature of live video more generally. After experiencing a live video feed of themselves or of nearby events, two-year-old children were subsequently more likely to use other live video and even photographs as a source of information about real-world events, such as the location of hidden objects (Troseth, 2003; Troseth & DeLoache, 1998). During video chat calls, the self-view provides children with similar live video of themselves. Experience with the self-view may similarly scaffold children's understanding of video images as representational, and directly relevant to real-world events.

How do children learn that it is not possible to feel touch or physically pass objects through the screen? Children's first-person experience is likely relevant, and sufficient evidence of this lack of ability. Touch and physical interaction (e.g. passing toys back and forth) is common in parents' play with young children, as well as in play between siblings (Hay, 1979; Lamb, 1978; Yu & Smith, 2013). The fact that this sort of physical interaction is impossible during video chat is salient in observations of children's video chat calls: For example, parents and children use novel forms of pretend play to replace activities in which objects would typically be exchanged (e.g. Grandma pretends to feed a blueberry to a toddler through the camera; child's parent feeds a blueberry to the child at the appropriate time; McClure & Barr, 2016; McClure et al., 2018). First-person experience also provides other sources of feedback: When children touch the screen, they feel only its smooth glass surface, not the feeling of people or objects depicted in the image. When their video chat partner touches the screen or camera, children experience the lack of tactile sensation. First-person experience of other perceptual

limitations allows infants to understand the limitations of others: Infants given experience wearing an opaque blindfold treated others who were blindfolded as though they could not see, following their gaze significantly less than infants who were not given this experience or were given experience with a transparent blindfold (Meltzoff & Brooks, 2008). Similarly, children's experience with the limitations of video chat may allow them to understand that these same limitations apply to others.

Input from parents likely also helps scaffold children's early understanding of the affordances of video chat. Parents typically accompany infants and young children during video chat sessions (McClure et al., 2015), and have been observed to use mental state language to help explain the video chat partner's perspectives or limitations (e.g. "She can't see it... turn [the device] this way so she can see", McClure et al., 2018). These types of rich verbal interactions may scaffold children's understanding of the video chat platform, and potentially also support the development of theory of mind (McClure et al., 2018).

Future directions: The impact of video chat on thinking about pre-recorded video

We compared children's reasoning about video chat to their reasoning about in-person interaction, and about a photograph – allowing us to compare video chat to a baseline stimulus that was clearly real, and clearly representational. In future work, it would be informative to compare children's reasoning about video chat to their reasoning about pre-recorded video – a dynamic but non-interactive representational medium.

This comparison would provide a foundation for exploring the impact that extensive experience with video chat may have on children's understanding of pre-recorded video. In particular, during the time when seminal studies on children's understanding of television were

performed (e.g. Flavell et al., 1990), the children tested had almost certainly never experienced an on-screen character that could see, hear and respond to them. At the time, video chat did not exist, and while two-way closed-circuit television was possible, this technology was not commonly available to children. It seems therefore plausible that if children today were asked if characters in pre-recorded videos could see or hear them, they would have more uncertainty about this than children in prior eras. Children's extensive experience with video chat may lead them to more seriously entertain the possibility that characters on television can see and hear them, because they know that some people on-screen do have this capacity.

Conclusion

Overall, our data show that by four years of age, children understand the unique ways that video chat allows for and limits perception and physical interaction. This understanding provides a foundation for effective use of video chat by children in early education and social interaction. As video chat is now a major part of young children's lives, it will be important for future work to explore the emergence of this distinct concept of video chat in early childhood, as well as the potential impact of video chat on children's developing theory of mind.

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