Children understand communication intuitively but indirect communication makes them think twice – Evidence from pupillometry and looking patterns

Cornelia Schulze^{1,2} and David Buttelmann³

¹Department of Educational Psychology, Faculty of Education, University of Leipzig

²Leipzig Research Center for Early Child Development, Leipzig, Germany

³Department of Developmental Psychology, Institute of Psychology, University of Bern

Author Note

Cornelia Schulze <https://orcid.org/0000-0001-9151-4792>

David Buttelmann <https://orcid.org/0000-0002-0915-7114>

Correspondence concerning this article should be addressed to Cornelia Schulze, Department of Educational Psychology, Faculty of Education, University of Leipzig, Marschnerstraße 31, D-04109 Leipzig, Germany. Email: cornelia.schulze@uni-leipzig.de

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Abstract

Interpreting a speaker's communicative acts is a challenge children are facing permanently in everyday life. In doing so, they seem to understand direct communicative acts more easily than indirect communicative acts. The present study investigated which step in the processing of communicative acts might cause difficulties in understanding indirect communication. To assess the developmental trajectory of this phenomenon, we tested 3- and 5-year-old children ($N=105$) using eyetracking and an object-choice task. The children watched videos that showed puppets during their every-day activities (e.g., pet care). For every activity, the puppets were asked which of two objects (e.g., rabbit or dog) they would rather have. The puppets responded either directly ("I want the rabbit") or indirectly ("I have a carrot"). Results showed that children chose the object intended by the puppets more often in the direct- than in the indirect-communication condition, and 5-year-olds chose correctly more than 3-year-olds. However, even though we found that children's pupil size increased while hearing the utterances, we found no effect for communication type before children had already decided on the correct object during object selection by looking at it. Only after this point, that is, only in children's further fixation patterns and reaction times did differences for communication type occur. Thus, although children's object-choice performance suggests that indirect communication is harder to understand than direct communication, the cognitive demands during processing both communication types seem similar. We discuss theoretical implications of these findings for developmental pragmatics in terms of a dual-process account of communication comprehension.

Keywords: indirect communication; relevance inference; pupil dilation; cognitive demands; direct communication; intentionality

Understanding others' intentions in communication is both – a developmental milestone and an everyday event. That is, throughout our day, we hear many communicative acts directed at us, and our task as recipients is to infer the communicator's intention: What she wanted us to know or do. Sometimes these intentions are made abundantly clear. To my colleague I might say, "Please, close the window" and thus tell her directly and explicitly what I want her to do. More often, however, these intentions are stated indirectly, for politeness and face-saving reasons (Brown & Levinson, 1987; Holtgraves, 1998) or because we do not just want to give orders but reasons for our assertions (Francik & Clark, 1985; Gibbs, 1986). Thus, I might say "It's rather cold in here", indirectly asking the colleague to close the window. In doing so, I produce a relevance implicature – an indirect communicative act in which the actual meaning needs to be inferred.

From prior research, we know that children understand direct communicative acts better than indirect ones. That is, in studies testing both direct and indirect communicative acts, 3- to 8-year-old children typically were shown pictures and a dialogue was narrated (e.g., a series of pictures showing a boy at the kitchen table asking the mother whether he could have some cookies and the mother answering, "Those cookies are for our guests tonight"; Elrod, 1987; Bucciarelli et al., 2003; Bosco et al., 2013). Mostly, children have to explain why the mother said that (e.g., the boy could not eat cookies because they were saved for the guests) or point to one of several end-state-pictures (e.g., the boy eating cookies, the boy doing something else, et cetera). Children explain the speaker's intention better and choose the end-state-picture more correctly after hearing a direct communicative act compared to hearing an indirect communicative act (Bosco et al., 2013; Bucciarelli et al., 2003; Elrod, 1987).

Typically, children's comprehension of indirect communicative acts improves with age. While preschoolers and younger children fail, only school-aged children understand

indirect communication involving such relevance implicatures as the one described above (Bucciarelli et al., 2003; de Villiers et al., 2009; Elrod, 1987; Loukusa et al., 2007, 2017; but see Schulze et al., 2013, and 2020 for 3-year-olds' successful performance in a simplified paradigm).

However, these findings on children's comprehension of direct and indirect communicate acts involving relevance implicatures are based on behavioral and explicit measures – that is, the outcome of the processing of these communicative acts. To the best of our knowledge, there is a lack of developmental studies investigating the processing demands before the actual explicit behavioral outcome. More specifically, it is unknown if and when in the time course of processing a specific cognitive effort (e.g., more attentional demands or additional processing time) is associated with the interpretation of indirect communicative acts compared to direct communicative acts in childhood. In adults, different methods yielded mixed results: self-paced reading studies sometimes found that indirect communication required longer processing (Hamblin & Gibbs, 2003; see also Holtgraves, 1994, for no systematic difference in reaction times see Holtgraves 1999; see also Ruytenbeek, 2017 for a review). EEG-studies found that indirect communication was actually easier to understand (Coulson & Lovett, 2010; see also van Ackeren et al., 2012) – at least, when the context eased the interpretation (Gisladottir et al., 2015, see also Gisladottir et al., 2018).

Of utmost relevance for the current study is the finding of larger pupil dilation in adults when they were shown a picture of closed window and heard an indirect request ("It's very hot in here") compared to when they heard a literal statement ("It's very nice in here"). Interestingly, no differences between both utterance types were found during hearing the utterances, the pupil dilation difference occurred only 1.5 seconds after hearing the critical word (e.g. hot vs nice) and persisted several seconds after hearing the utterance (Tromp et al., 2016). Thus, this finding suggests higher processing demands for indirect communicative

acts after hearing them (see also Holtgraves, 1994, 2008).

The current study aimed at investigating processing demands of indirect communicative acts involving relevance implicatures compared to direct literal statements using pupil dilation and looking behavior measures. We addressed this question in 3- and 5-year-old children using an eyetracking paradigm based on the task by Schulze, Grassmann, and Tomasello (2013). We included 3-year-old children since children this age were the youngest who have demonstrated an understanding of verbal relevance implicatures (Schulze et al., 2013, 2020; Tribushinina, 2012). We further tested 5-year-old children given major developmental effects between 3- and 5-year-old children concerning relevance inferences as well as other communication-based inferences (e.g., ad hoc quantity inferences, scalar inferences, see Wilson & Katsos, 2020; Wilson, 2020).

The present study had two main research questions. The first question was whether there were differences in the processing demands of direct versus indirect communicative acts in children, and if yes, when in the sequence of processing they would occur. Given that this question has not been addressed in the developmental literature, we used a variety of measures to explore relevance implicature comprehension. Specifically, we wanted to go beyond the previously measured behavioral outcome difference in the accuracy of object-choice or meaning explanation (Bosco et al., 2013; Bucciarelli et al., 2003; Elrod, 1987). Thus, we were also interested in differences in reaction times as participants should choose faster when hearing direct communicative acts than when hearing indirect communicative acts (Gibbs, 2002; Grice, 1989; Hamblin & Gibbs, 2003; Searle, 1975; Sperber & Wilson, 1995).

More importantly, differences during processing could occur with respect to the cognitive effort both communication types require and might be evidenced by pupil dilation and looking behavior (for reviews concerning pupil dilation as a measure of cognitive effort

see Hepach & Westermann, 2016; Jackson & Sirois, 2009; Laeng et al., 2012). Based on prior adult findings, we expected that children's pupils should dilate more during or after hearing indirect compared to direct communicative acts (Tromp et al., 2016). Thus, we measured children's pupil dilation before, during and after the utterances.

Finally, given that studies on children's looking behavior in other pragmatic tasks (such as scalar implicature comprehension or reference resolution) found elaborate fixation patterns for utterances that required inferencing (Graham et al., 2014; Huang & Snedeker, 2009; Khu et al., 2019; Nadig & Sedivy, 2002; Nilsen et al., 2008; Yoon et al., 2015), we expected to find more elaborate fixation patterns for indirect compared to direct communicative acts.

The second research question of the present study was whether differences in children's individual processing parameters (pupil dilation, fixation patterns) resulted in differences in their behavioral outcome measure, namely, their object-choice (cf., Tromp et al., 2016 for correlations between adults' pupil size and their behavioral response).

2.1 Method

2.1.1 Participants

One hundred and five monolingual German-speaking children participated in this study. There were two age groups: 3-year-old children with a mean age of 3 years; 6 months; 11 days (range: 3;3,23 - 3;8,6; 52% female), and 5-year-old children with a mean age of 5 years; 6 months; 25 days (range: 5;3,25 - 5;8,12; 49% female). Fourteen additional children were tested but had to be excluded from the final sample due to equipment failure ($n=6$; three 3- and three 5-year-olds), the child being uncooperative (dropout, $n=5$ 3-year-olds), the child turning out to be bilingual ($n=2$ 3-year-olds), or due to our data handling criteria ($n=1$ 3-year-old). This study was conducted in accordance with the ethical standards laid down in the Declaration of Helsinki and the standards of the local ethics committee of the University of

[blinded for review]. The children's parents had previously agreed to their children participating in studies on child development in a mid-sized German city. In addition to their general agreement, parents signed a consent form for participating in the current study prior to testing. Each child received a small toy as gratification.

2.1.2 Materials and set-up

Throughout the study, the child sat at a table in front of a 25 inch computer screen (resolution 2560 x 1440 pixel), with a distance of about 60 cm between the child and the screen. In front of the child there was a computer keyboard covered by a wooden frame with two push buttons. The table was surrounded by three partition walls and shielded from direct light. The eye tracking unit (SMI eye tracker RED250mobile, SensoMotoric Instruments, 8.2) was positioned below the monitor and measured children's eye movements and pupil diameter at a sampling frequency of 60 Hz. Stimulus presentation and data recording were carried out using SMI Experiment Center 3.7.60 and BeGaze 3.7.42. The experimenter sat behind the partition walls out of the child's view and operated the technical equipment.

All sessions were videotaped with a camera that stood behind the child (to the left).

2.1.3 Design

All children saw a communication task consisting of eight trials in two between-subjects conditions. The children were randomly assigned to one of the two conditions (Direct Communication Condition, Indirect Communication Condition, see below). Each trial consisted of four phases (see Figure 1).

Figure 1*Overview of Test Stimuli and Trial Phases in the Communication Task*

Note. Blue frames indicate pupil dilation measurement, yellow frame indicates looking behavior measurement. The conditions differed in the utterance phase where the intended object was either labeled directly (direct communication condition) or only indirectly hinted at (indirect communication condition). (a) The context phase's video stimulus was followed by a fixation cross (1000ms) and a still frame of a puppet (2000ms) that served as baseline for the pupil dilation measure. (b) During the utterance phase's video stimulus, pupil dilation was measured. This was followed by the same still frame of the puppet (2000ms), during which the post-utterance pupil dilation measure was taken. (c) During the object-choice phase, children saw the object-choice stimulus (picture containing the trial's two object-choice options). Children's looking behavior was measured until the children chose an object. A third still frame of the puppet (2000ms), during which the post-choice pupil dilation measure was taken followed. (d) A play phase concluded each trial.

2.1.4 Procedure

General warm-up. In a 15-minute warm-up phase, the child, her parent, and the experimenter played in a warm-up room in order to make the child feel comfortable in the lab and to brief the parents about the study. The child and the experimenter then moved to the testing room. In the testing room, the experimenter sat next to the child and explained that the child would watch videos of a puppet theatre on the computer screen and asked the child to sit in the chair across the screen (see Figure 2). To familiarize the child with the buttons that were used to record the child's object-choice, the child saw four warm-up trials showing colored smiley (e.g., blue and green) faces and were asked to choose one by pushing the

button on the left or right side. While the experimenter labeled the buttons as the left or right button, she additionally pointed to the button and the corresponding side of the computer screen. For instance, the experimenter said, “Look, [name of the child], here you can see a blue smiley [point to the left side of the screen] and here you can see a green smiley [point to the right side of the screen]. To choose the blue smiley [point to blue smiley], you push the left button [point to appropriate button] and for the green smiley [point to green smiley], you push the right button [point to appropriate button]. Now try pushing the button for the blue smiley [point to smiley]!”). If the child pushed the wrong button, the experimenter explained again which button corresponded to which side of the screen and re-ran the warm-up trial.

Figure 2

Illustration of the Study Set-up

Task-specific warm-up. In order to familiarize the children with the structure of the task, the experimenter then explained that the child would now see two puppets showing their daily activities and that at certain time points the puppets would need the child’s help. The child then saw two further warm-up trials were either of the two puppets asked her for one of two objects displayed on the screen (e.g., a truck and a ball). To make sure that children understood that their task was to press a button to choose an object for the puppet, the experimenter’s instructed the child accordingly (e.g., “For the truck, you push the left button and for the ball you push the right button [again pointing to the objects on screen and the

corresponding buttons in turn]. And the puppet wanted the ball; now try pushing the button for the ball!”). When the child chose correctly, the experimenter started the next video clip showing the puppets thanking the child. When the child chose incorrectly, the experimenter paused the experiment and explained to the child that the puppets really wanted a certain object (which they had explicitly asked for in the warm-up trials) and that the child should choose this object. Thus, the task-specific warm-up familiarized children with the situation of choosing one object (that the puppet wanted) for the puppet by pressing a button when the object-choice stimulus appeared. After two trials, the experimenter moved behind the partition walls and started the 5-point calibration that showed a duck making jingling noises moving across the screen. The experimenter then started the communication task.

Communication task

(a) Context phase. In the context phase, the child saw pre-recorded video clips showing the puppets behind a table and depictions of two objects in front of the puppets. The puppets explained which action they were going to perform and introduced the two alternative options. That is, when they wanted to do pet care, one puppet asked which pets they could take care of and the other explained that they could choose between a rabbit and a dog (pointing to each pet placed in front of the puppets on the table). The puppet then asked the other whether she would rather take care of the rabbit or the dog.

A blank screen with a central fixation cross (1000 ms) and a still frame of the puppet (2000 ms) followed the context video.

(b) Utterance phase. The child then saw a video of the puppet placed centrally between the two alternative options. The puppet’s utterance depended on the condition.

Direct Communication Condition. The puppet directly communicated her goal by labeling the intended object, saying for instance the German equivalent of “I want / do not want the rabbit”, thus explicitly mentioning the object the child should choose by pushing the

appropriate button (for an overview of utterances see appendix).

Indirect Communication Condition. The puppet indirectly hinted at her goal, saying for instance the German equivalent of “I have / do not have a carrot”, thus not mentioning any of the actual options the child had to choose from but uttering a pre-condition for taking care of one of the two pets.

Based on Schulze et al. (2013, see also 2020), we included positive and negative statements in the utterance phase of both conditions. The purpose of the negative statements was to account for possible simple associations between the label used in the utterance (e.g., rabbit or carrot) and the objects which the children had to choose from.

A still frame of the puppet (2000 ms) followed the utterance video.

(c) Object-choice phase. The child then saw a white screen with the two alternative options depicted on either side of the screen (object-choice stimulus) to choose from (note that children had practiced this response format during the task-specific warm-up). In the first 10 seconds no instruction was given. If the child did not choose during this time, the experimenter explained that the child should now choose one option for the puppet (“Which one did the puppet want, which button do you need to push?”). If the child did not choose during a further 10-second interval, the experimenter said, “Look, the puppets have a rabbit and dog, to give the puppets the rabbit, you push the left button, to give the puppets the dog, you push the right button. The puppets said: “I want the rabbit” / “I have a carrot”. Which one do you give to puppets?” If the child failed to choose during a further ten seconds, the experimenter proceeded with the next trial, saying, “Okay, there will be another story in a moment, pay close attention!”

A still frame of the puppet (2000 ms) followed the object-choice stimulus.

(d) Play phase. Irrespective of the child’s actual answer, the child then saw a video in which the puppets thanked the child and went on to perform the action (e.g., feeding the

rabbit with a carrot).

2.1.5 Coding and reliability

An object was coded as chosen when the child pushed the corresponding button. This choice as well as children's reaction times were recorded by the SMI eye-tracking software and entered into a data file. An independent, blind coder additionally coded the whole sample's object-choice from video tapes. There was full agreement between the data entered by the system and that of the blind coder.

2.1.6 Data handling

2.1.6.1 Quality of the eyetracking data and exclusion criteria

Trials in which the children's reaction times for choosing an object exceeded two standard deviations of the condition's mean reaction time were excluded from all further analyses (i.e. 210 trials in which no reaction time was recorded and 45 trials in which children's reaction time exceeded the two standard deviations criterion). Thus, 585 of 848 possible trials across all 105 participants could be analyzed.

Data pre-processing was carried out using R (version 3.5.2). Each child's raw data were exported as text-file from SMI BeGaze (version 3.7.42). Following Hepach, Vaish, & Tomasello (2012), we excluded individual samples if the children's pupil dilation data in this sample differed from the preceding and subsequent sample's measures by 0.9 percent. Secondly, missing samples were linearly interpolated when the gap between two samples did not exceed four samples. We averaged the gaze point data for x- and y-coordinates from both eyes for fixation events. Next, we averaged the pupil dilation data from both eyes for fixation events. The averaged data were then filtered and interpolated again using the same methods as described above (see also Vaish et al., 2018). Due to data loss, pupil dilation analyses were carried out with a subsample of 83 to 89 children, and looking behavior analyses were carried out with a subsample of 94 to 99 children (see appendix for an overview of excluded trials

and the remaining sample size for each measure).

2.1.6.2 Pupil dilation and gaze data

Still frames. For each trial, children's *pupil dilation* during each of the three *still frames* (baseline before utterance, post-utterance and post-choice) was averaged to account for the cognitive effort associated with utterance processing and object choice. We then averaged these means across the eight trials. We also created a *pupil-dilation difference score (PDDS)* for each trial by subtracting the baseline pupil dilation mean from the post-utterance pupil dilation mean in order to measure children's increase or decrease of pupil dilation triggered by hearing the utterances. These difference scores were then averaged across the eight trials.

Utterance stimulus. As suggested by Vaish, Hepach, and Grossmann (2018), we calculated children's mean pupil dilation during the first seven samples of the utterance stimulus phase as the baseline value. In order to continuously assess *children's pupil dilation (and thus, their cognitive effort) during hearing the utterances*, we then calculated each sample's pupil dilation difference by subtracting the baseline value from the sample's raw value (see also Vaish et al., 2018). Given that the actual utterance took only 2 seconds during the 6-seconds long utterances stimulus (2 seconds before the actual utterance (no language or movement), 2 seconds during the actual utterance (language and movement), and 2 seconds after the actual utterance (no language or movement)), we averaged children's continuous data for these three time windows per trial and then averaged their data across the eight trials.

Object-choice stimulus. To explore children's processing during object choice (as evidenced by their looking behavior), we defined two areas of interest (AOIs) of identical width (620 px) and height (600 px) around the two options in the object-choice stimulus. All measures were taken from the onset of the object-choice stimulus to the time point when the child chose an object as evidenced by his or her reaction time. Children's looking time at the

two AOIs was calculated separately by multiplying the number of AOI-Hits (samples when children's gaze points were within the margins of the predefined AOI) by 16.67 (as we sampled children's eye movements with 60 Hz equaling 60 samples in 1000 ms, thus one sample equaled 16.67 ms). We then calculated a *differential looking score (DLS)* by subtracting the time spent looking to the trial's incorrect object's AOI from the looking time to the correct object's AOI and dividing the result by the overall looking time at both AOIs. We then averaged that score across the eight trials. This resulted in a score between -1 and 1, in which a positive score means that the child spent more time looking at the correct object than at the incorrect object.

For the object-choice stimulus, we then calculated the *latency* for looking at the correct object. For each trial, we counted the number of samples from the start of the object-choice stimulus until the children's gaze point first entered the AOI with the correct object (after having looked somewhere else thus excluding AOI-hits when children already looked at the AOI at the onset of the object-choice stimulus). We then multiplied this number by 16.67 (to account for their looking time, see also above). We then averaged the latencies across all trials per child. For each trial, we also counted the *number of fixations* in each AOI by summing up the number of samples when children's gaze points newly entered either of both AOIs. We then averaged the numbers of fixations across all trials per child.

2.1.6.3 Reaction time and object-choice data

We calculated children's mean proportion of trials in which they chose the correct object and children's mean reaction times in all trials.

2.2 Results

To control for effects due to the valence of the utterances we ran repeated-measures ANOVAs with statement type (positive, negative), communication type (direct, indirect), and age (3, 5) as independent variables and (separately) measures of pupil dilation, PDDS, latency,

fixations, reaction times, and object choice as dependent variables. The ANOVAs revealed that statement type had no effect on children's pupil dilation in baseline, post-utterance, and post-choice still frames, PDDS, their pupil dilation during the three time windows of the utterance stimulus, latency for looks to the correct object and number of fixations on both objects in the object-choice stimulus, and their reaction times in the object choice (all $ps > .24$). For children's accuracy in the object choice, the ANOVA revealed a marginally significant effect of positive vs. negative statements ($F(1,86) = 3.927, p = .051, \eta^2 = .044$). That is, children had a tendency to choose more correctly after hearing positive statements ($M = 79.4, SD = 33.2$) compared to hearing negative statements ($M = 68.9, SD = 40.5$). However, no interaction with statement type was found for accuracy. There was further a main effect of statement type on children's differential looking scores (DLS) during the object-choice stimulus ($F(1,79) = 11.607, p = .001, \eta^2 = .128$). That is, children looked more to correct than the incorrect object after hearing positive statements ($M = .35, SD = .40$) compared to hearing negative statements ($M = .09, SD = .50$). However, no interaction with statement type was found for children's DLS.

2.2.1 Pupil dilation and gaze data

Cognitive effort before and after the utterance and after object choice. To account for the cognitive effort associated with processing the utterances and choosing an object, we analyzed children's pupil dilation during the three still frames. A 3 (time: baseline, post-utterance, post-choice) x 2 (age group: 3-year-olds, 5-year-olds) x 2 (communication type: direct communication, indirect communication) repeated-measures ANOVA revealed a significant interaction of time and age group ($F(2,168) = 3.868, p = .023, \eta^2 = .044$; see Figure 3) and a significant effect for time ($F(2,168) = 132.883, p < .001, \eta^2 = .613$). No effect of communication type was found ($F(1,84) = 0.161, p = .689, \eta^2 = .002$).

Figure 3

Children's Mean Pupil Dilation at the Three Time Points by Age Group

Note. Graph shows the data distribution in a violin plot, the open circle indicates the median with a vertical bar indicating each median's 95% confidence interval. (Graph built using PlotsOfData, see Postma & Goedhart, 2019)

Concerning the interaction between time point and age, post-hoc paired samples *t*-tests separated by age group showed no difference between post-utterance and post-choice measures (3yo: $T(45) = 1.319, p = .194$, Cohen's $d = .09$; 5yo: $T(42) = 1.173, p = .247$, Cohen's $d = .11$; Bonferroni-corrected significance level $\alpha = 0.125$). However, there was difference between baseline and post-utterances measures which seemed more pronounced in the 5-year-old children ($T(41) = 11.912, p < .001$, Cohen's $d = .80$; Bonferroni-corrected significance level $\alpha = .0125$) than in the 3-year-old children ($T(45) = 9.742, p < .001$, Cohen's $d = .63$; Bonferroni-corrected significance level $\alpha = .0125$).

To further investigate this possible difference between age groups with a baseline-adjusted value of children's post-utterance pupil dilation, we calculated a difference score subtracting the post-utterance values from the baseline value (pupil-dilation difference score, *PDDS*). A Univariate ANOVA with the *PDDS* as dependent variable and age group and communication type as independent factors revealed no effect for communication type ($F(1)$

$= .742, p = .392, \eta^2 = .009$). However, there was a significant effect for age group ($F(1) = 8.827, p = .004, \eta^2 = .096$): Pupil dilation differences between baseline and post-utterance (PDDS) was greater in 5-year-olds ($M = .31, SD = .15$) than in 3-year-olds ($M = .21, SD = .15$; see Table 1 for an overview of the data).

Table 1

Overview of Descriptive Statistics for all Measures as a Function of Communication Type and Age Group.

	3-year-olds		5-year-olds	
	Direct communication	Indirect communication	Direct communication	Indirect communication
PDDS (SD) in mm	0.23 (0.13)	0.20 (0.15)	0.27 (0.16)	0.35 (0.13)
PD change before actual utterance (SD) in mm	-0.01 (0.12)	0.04 (0.10)	0.07 (0.13)	0.04 (0.12)
PD change during actual utterance (SD) in mm	0.06 (0.18)	0.13 (0.15)	0.18 (0.16)	0.12 (0.21)
PD change after actual utterance (SD) in mm	0.01 (0.19)	0.00 (0.12)	0.20 (0.14)	0.14 (0.23)
Latency (SD) in sec	0.93 (0.87)	1.31 (1.68)	0.63 (0.31)	0.71 (0.33)
Number of fixations (SD)	12.9 (5.8)	22.4 (14.4)	6.4 (2.8)	8.0 (3.2)
DLS (SD)	0.28 (.35)	0.07 (.26)	0.46 (.26)	0.14 (.40)
RT (SD) in sec	6.06 (4.30)	14.11 (9.81)	2.61 (0.73)	3.62 (1.43)
Object-choice (SD) in %	80.5 (28.6)	59.5 (28.8)	96.1 (7.0)	70.2 (25.7)

Note. PDDS: pupil-dilation difference score (mean difference between baseline pupil dilation and post-utterance pupil dilation), PD change: mean change in pupil dilation before, during, and after actual utterance within the utterance stimulus, DLS: differential looking score (score for how much of their overall looking time children spent on looking to the correct object), RT: reaction time.

Cognitive effort during utterance processing. Next, we analyzed children's pupil dilation change during the utterance stimulus during three time windows (2 seconds before

the actual utterance, 2 seconds during the actual utterance, and 2 seconds after the actual utterance, see Figure 4). A Repeated Measures ANOVA with the averaged incremental change of children's pupil dilation as dependent variable and age group and communication type as independent factors revealed an interaction of time window and age group ($F(2) = 9.200, p < .001, \eta^2 = .104$) and main effects of time ($F(2) = 17.272, p < .001, \eta^2 = .179$) and age group ($F(1) = 8.609, p = .004, \eta^2 = .098$), but no effect for communication type ($F(1) = .049, p = .825, \eta^2 = .001$). Post-hoc independent samples t-tests with age group as between-subjects-factor and change of children's pupil dilation as dependent variable separately for the three time windows during the utterance stimulus revealed that the age effect occurred only in the last time window, that is, immediately after hearing the utterance ($T(81) = 4.323, p < .001$, Cohen's $d = .95$; Bonferroni-corrected significance level $\alpha = .0167$).

Figure 4

Children's Mean Pupil Dilation Change During the Three Time Windows Within the Utterance Stimulus by Age Group

Object-choice processing as evidenced by looking behavior. Further, we analyzed children's looking behavior during the object-choice stimulus until they chose an object to further explore their search- and decision-behavior during the object choice (after having heard the utterances). The first analysis concerned children's latency for looking at the correct object. A Univariate ANOVA with latency as dependent variable and age group and

communication type as independent factors revealed a significant effect of age group ($F(1) = 4.834, p = .030, \eta^2 = .049$), that is, 5-year-olds ($M = .67, SD = .32$) looked faster to the correct object than did 3-year-olds ($M = 1.14, SD = 1.38$; see Table 1). However, no effect of communication type was found ($F(1) = 1.256, p = .265, \eta^2 = .013$).

A Univariate ANOVA with number of fixations on both AOIs (i.e., correct object vs. incorrect object) as dependent variable and age group and communication type as independent factors revealed a significant interaction of age group and communication type ($F(1) = 5.156, p = .026, \eta^2 = .054$) and significant main effects of age group ($F(1) = 35.256, p < .001, \eta^2 = .281$) and communication type ($F(1) = 10.127, p = .002, \eta^2 = .101$; see also Table 1). Post-hoc independent samples t-tests revealed that the communication type effect occurred only in the 3-year-olds ($T(46) = 3.145, p = .003$, Cohen's $d = .93$; Bonferroni-corrected significance level $\alpha = .025$) but not in the 5-year-olds ($T(44) = 1.801, p = .078$, Cohen's $d = .57$; Bonferroni-corrected significance level $\alpha = .025$).

In order to assess whether children spent more time looking to the correct than to the incorrect object, we calculated a differential looking score (DLS). A Univariate ANOVA with DLS as dependent variable and age group and communication type as independent factors revealed a significant main effect for communication type ($F(1) = 16.644, p < .001, \eta^2 = .149$). That is, children of both age groups looked longer to the correct object than the incorrect object after hearing a *direct* utterance ($M = .37, SD = .32$) than after hearing an *indirect* utterance ($M = .10, SD = .34$; see Table 1).

2.2.2 Reaction time and object-choice data

Finally, we analyzed children's object-choice. A Univariate ANOVA with children's mean reaction time until choosing an object as dependent variable and age group and communication type as independent factors revealed a significant interaction of age group and communication type ($F(1) = 10.182, p = .002, \eta^2 = .092$) and significant main effects of

age group ($F(1) = 40.031, p < .001, \eta^2 = .284$) and communication type ($F(1) = 16.908, p < .001, \eta^2 = .143$, see also Table 1 and Figure 5). Post-hoc independent samples t-tests separately for age group revealed that children reacted faster after hearing direct than after hearing indirect utterances. This effect was more pronounced in 3-year-olds, that is, their difference in reaction time was larger than that of 5-year-old children (3yo: $T(52) = 3.996, p < .001$, Cohen's $d = 1.08$; 5yo: $T(49) = 3.247, p = .002$, Cohen's $d = .91$; Bonferroni-corrected significance level $\alpha = .025$).

Figure 5

Bar Chart Presenting Children's Mean Reaction Times and Standard Errors as a Function of Age Group and Communication Type

Note. The reaction time bars (in blue and red) include the latency for the first look to the correct object as a bar chart (grey) and the descriptive statistics for children's mean number of fixations (*FIX*) and differential looking score (*DLS*) during those reaction times.

A Univariate ANOVA with children's mean percentage of trials in which they chose the correct object as dependent variable and age group and communication type as independent factors revealed significant main effects for communication type ($F(1) = 23.739, p < .001, \eta^2 = .190$) and age group ($F(1) = 7.521, p = .007, \eta^2 = .069$), but no interaction between these two variables ($F(1) = .270, p = .605, \eta^2 = .003$, see Figure 6). That is, children chose more correctly after hearing direct than indirect utterances (direct communication: $M =$

88.1, $SD = 22.2$; indirect communication: $M = 64.7$, $SD = 27.6$) and 5-year-olds did so more than 3-year-olds (3yo: $M = 69.2$, $SD = 30.3$; 5yo: $M = 82.4$, $SD = 23.1$).

Figure 6

Children's Mean Percentage of Correct Object-Choice Trials by Age Group and Communication Type.

Note. Graph shows the data distribution in a violin plot, the open circle indicates the median with a vertical bar indicating each median's 95% confidence interval. (Graph built using PlotsOfData, see Postma & Goedhart, 2019)

2.2.3 Influence of utterance processing before the object-choice on choice

behavior

Next, we analyzed to what degree the processing of the utterances affected children's behavioral response. Regarding the pupil dilation data, there were no effects of communication type but of age group. Thus, we split our data for age group and ran a stepwise linear regression with children's mean percentage of correct object-choice trials as dependent variable and children's averaged PDDS and their pupil dilation immediately after hearing the utterance as dependent variables. For the 3-year-olds, the regression revealed a weak significant influence of their pupil dilation immediately after hearing the utterance on

object-choice performance and no effect of PDDS (see Table 2). For the 5-year-olds, the regression revealed a significant effect of PDDS on object-choice performance, explaining 15.3% of the data. Including the pupil dilation right after hearing the utterance (during the utterance stimulus) explained an additional 13.4% of the variance in 5-year-olds' eventual object-choice.

Table 2

Linear Model of Predictors of Children's Object-Choice During Utterance Processing.

		<i>B (CI)</i>	<i>SE B</i>	β	<i>p</i>	R^2	ΔR^2
3- Year- Olds	Model 1						
	PD change after utterance	-.636 (-1.261, -.012)	.309	-.310	.046	.096	
	Model 1						
5- Year- Olds	PDDS	-.526 (-.945, -.107)	.207	-.391	.015	.153	
	Model 2						
	PD change after utterance	.380 (.079, .681)	.148	.367	.015	.287	.134
	PDDS	-.549 (-.940, -.158)	.192	-.408	.007		

Note. PDDS: pupil-dilation difference score (mean difference between baseline pupil dilation and post-utterance pupil dilation in mm), PD change: mean change in pupil dilation after the actual utterance within the utterance stimulus in mm.

2.2.4 Relation of looking behavior during object-choice on choice behavior

To validate our looking data and to explore whether children's looking behavior predicted their object-choice, we ran a stepwise linear regression with children's mean percentage of correct object-choice trials as dependent variable and children's latency until looking at the correct object, their number of fixations into both AOIs, and their DLS as independent variables split for age group and communication type. The regression analysis

revealed that in both age groups and communication types the DLS consistently predicted children's object-choice (see Table 3). Thus, the more children looked at the correct object, the more correctly they chose this object.

Table 3

Linear Model of Predictors of Children's Object-Choice During Object Selection.

Communication Type		B (CI)	$SE\ B$	β	p	R^2	ΔR^2
3-Year-Olds	Indirect	Model 1					
		DLS	.631 (.275, .986)	.172	.590	.001	.349
		Model 2					
		DLS	.708 (.366, 1.051)	.166	.663	< .001	.450 .102
		Latency	.00005 (.000001, .0001)	.00003	.327	.046	
	Direct	Model 1					
		DLS	.477 (.103, .851)	.179	.522	.015	.273
		Model 2					
		DLS	.611 (.258, .964)	.168	.669	.002	.454 .181
Fixations	.023 (.003, .043)	.009	.451	.025			
5-Year-Olds	Indirect	Model 1					
		DLS	.484 (.245, .722)	.115	.668	< .001	.446
	Direct	Model 1					
		DLS	.146 (.042, .251)	.050	.546	.009	.298

Note. DLS: differential looking score (score for how much of their overall looking time children spent on looking to the correct object).

Including children's latency for looks to the correct object explained an additional 10.2% of children's variance in object-choice in the 3-year-olds' indirect communication condition only. Including the number of fixations explained an additional 18.1% of children's

variance in object-choice in the 3-year-olds' direct communication condition only. In 5-year-olds, neither of the additional variables significantly predicted their choice behavior.

General Discussion

In this study, we investigated whether there were differences in the processing demands of direct and indirect communication in 3- and 5-year-old children and whether these processing demands yielded different behavioral outcomes. Across age groups, children's behavioral responses differed between conditions: Children in the direct communication condition chose objects more correctly and chose faster than did children in the indirect communication condition. Thus, inferring the speaker's intent seems harder if the speaker asserted her intention indirectly.

Even though children's object-choice performance suggests that indirect communication is harder to understand than direct communication, the cognitive demands that are placed upon children when hearing direct and indirect communicative acts seem similar until a certain point in the processing of utterances. That is, we found no effects of communication type on children's pupil dilation during and after the processing of the utterances. Even children's latency for deliberate looks to the correct (i.e., intended) object was not influenced by communication type. Differences in children's looking behavior did occur only after children had already looked at the correct object. That is, only after already having reached the correct conclusion implicitly, children in the indirect communication condition showed more fixations at both AOIs, resulting in a lower differential looking score (fewer looks at the intended object), potentially evoking a less correct object-choice. Thus, the basal processing of direct and indirect communicative acts seems similar but indirect communication elicits a more elaborate object-choice. Following Kahneman's dual-system theory of thinking (Kahneman, 2011), we suggest that this result is a product of a dual-system processing of communication: system 1 thinking is a fast, intuitive process without

intentional decision-making. It is based on abstracted world knowledge and the resulting expectations about how people typically behave. This process provides an ongoing interpretation of what happens in the world. That is, a perceived (communicative) behavior activates associative memory, and this activation spreads through the memory system. This way, the perceiver is prepared for the things (words, behaviors) that typically occur in combination with the perceived behavior and these (communicative) behaviors are easily recognized. Unexpected events are interpreted in terms of emotional, causal, or situational coherence. system 2 thinking, however, is a slow and effortful way of thinking that requires attention and intention. Mostly being in a “comfortable low-effort mode, in which only a fraction of its capacity is engaged” (Kahneman, 2011, p. 24), and only if the interpretation of a behavior fails, system 2 processing is called for support (bottom-up). System 2 thinking then re-analyzes the behavior in the current context by activating attention and intentional interpretation with more detailed and specific processing. Little is known about which system is involved in processing communication. Kahneman remarks how he accidentally noticed that “mundane conversation apparently demanded little or no effort” (Kahneman, 2011, p. 34) and states that system 1 understands language (Kahneman, 2011, p. 74). Support for fast thinking in communication comprehension comes from research using event-related potentials occurring in EEG measurements or looking-time studies using eye-trackers (Breheny et al., 2013a, 2013b; Grodner et al., 2010; Hagoort & van Berkum, 2007; Sedivy, 2007; van Berkum, 2008). For example, several studies showed that within 200 to 300 milliseconds of hearing a contextually inappropriate word (that mismatches assumptions about the speaker, the world knowledge, or semantic or syntactical expectations), adult recipients start to integrate the new fact into their interpretation (see also Gisladdottir et al., 2018; Levinson, 2006; and Hagoort & van Berkum, 2007; and van Berkum, 2008 for reviews).

Our data suggest that communication is mainly processed in system 1 and that – up to a certain point in the processing sequence – there is no difference in the processing of direct and indirect communication. Rather all communicative acts are vague to some degree and are analyzed the same way at first. In the present study, for direct communication, the children used their system 1 to compare what they have heard in the utterance (e.g., “I want the the rabbit”) with the choice options (e.g., a dog and a rabbit). They found an object that completely matched the uttered label and thus, after having decided on the object implicitly, they chose this object without much consideration of the alternative option. In indirect communication, system 1 also generated an interpretation based on associations (e.g., between “carrot” and the rabbit). However, since in the utterance phase the choice options were never labelled, children could not confirm this choice via a direct match between the uttered label and the object they had chosen implicitly. Thus, after already having chosen the correct object with their eyes using on system 1, children started to explore both choice options as evidenced by their intense search behavior (higher number of fixations and differential looking score closer to zero compared to direct communication) using system 2 capacities. We thus suggest that children in this late phase of the processing of communicative acts actively reason about the speaker’s intentions *after* having understood the intention intuitively (cf., Egorova et al., 2013; Holtgraves, 2008; Nilsen et al., 2008).

Interestingly, it was specifically the 3-year-old children who exhibited the intense search behavior described above. Five-year-olds, in contrast, chose faster and had fewer fixations than the younger age group. They did, however, also showed greater pupil dilation during hearing the utterance, a greater difference in pupil dilation from baseline to post-utterance still frame, and a shorter latency to look at the correct object. This suggests an age-related difference in the depth of utterance processing (that, however, did not differ for communication type). Since the pupil dilation differences were most evident immediately

after hearing the utterance, we suggest that 5-year-olds already processed the utterance more deeply at this point in time possibly engaging more developed world knowledge and other context resources within system 1 interpretation. When the object-choice stimulus appeared, they already had reached an ascertained (implicit) conclusion, which resulted in fewer fixations, a faster reaction time, and a more correct object-choice.

Three-year-olds on the other hand, had not yet processed the utterance enough right after hearing it, thus, they might have been startled by the object-choice stimulus and only then started to integrate what was said with the overall question under discussion (which object to give to puppet based on her utterance). This interpretation is supported by the results of our regression analysis that revealed a significant influence of children's pupil dilation immediately after hearing the utterance on children's object-choice performance across both communication types. In 5-year-olds, pupil dilation (that is, cognitive effort) immediately after hearing the utterance explained nearly 15% of the variance in their object-choice behavior.

However, the finding that prolonged cognitive effort during the still frames (that is, 3 to 5 seconds after hearing the utterance) resulted in less correct object-choice suggests that prolonged cognitive effort negatively affected children's object-choice. We suggest that children might be trying too hard to make sense of the utterance they heard: Engaging system 2, they overthink their first implicit conclusion, which hinders their object-choice performance (cf., Talbert, 2017). In 3-year-old children, that is even the case immediately after hearing the utterance. While cognitive effort right after hearing the utterance seems to benefit 5-year-olds' object-choice performance, 3-year-olds might notice that they heard something strange (i.e., seemingly irrelevant) and start to think about it elaborately, which - comparably to our interpretation for 5-year-olds elaborate processing - does not seem to benefit 3-year-olds' object-choice performance. This suggests that their system 2 might not

yet be developed enough to come up with a coherent interpretation.

The regression analyses also suggest that implicit measures (pupil dilation, looking behavior) strongly correlate and predict explicit behavioral measures (object-choice). During object-choice, children's looking behavior (i.e., their DLS, which is a score for how much of their overall looking time children spent on looking to the correct object) predicted about 30%- 50% of the variance in children's object-choice performance. We suggest that those children, who intuitively chose an object after some but not too much cognitive effort (as evidenced by a greater pupil dilation right after having heard the utterance and a quick decline in pupil dilation in the seconds afterwards) then spent more time looking to the correct object during object-choice and then chose this object accordingly. That is, those children who trusted their gut feeling (and did not overthink it) looked to the correct object more and eventually also chose it.

The findings of the present study are in line with previous research on children's comprehension of indirect communication and other pragmatic phenomena. Like previous studies, we found a better performance for direct than for indirect communicative acts requiring comprehension of relevance implicatures (Bosco et al., 2013; Bucciarelli et al., 2003; Elrod, 1987). Reaction time differences that were previously only evidenced in adults (Hamblin & Gibbs, 2003), were found for children in our study. In line with previous developmental studies on other pragmatic tasks (such as scalar implicature comprehension or reference resolution, see: Graham et al., 2014; Huang & Snedeker, 2009; Khu et al., 2019; Nadig & Sedivy, 2002; Nilsen et al., 2008; Yoon et al., 2015), we also found elaborate fixation patterns for those utterances that required more inferencing, that is, for indirect communicative acts. Moreover, we replicated developmental effects concerning children's object-choice performance that is in line with the children's general development of pragmatic phenomena (e.g., ad hoc quantity inferences, scalar inferences, see Wilson &

Katsos, 2020; Wilson, 2020). Importantly, we extended those findings by showing age-related differences in a number of different measures of communication comprehension such as children's looking behavior and reaction times during object choice and also in their pupil dilation suggesting age-differences in cognitive effort during communication comprehension.

Besides these replications and extensions of adult findings to children, the present study is the first to show that children's processing of indirect communicative acts does not require extra cognitive effort compared to direct communicative acts as evidenced particularly by similar pupil dilations during and after hearing the direct and indirect statements. In adults, differences in pupil dilation after hearing the utterance had been found (Tromp et al., 2016). We also found an increase in pupil dilation immediately after hearing the utterance that, in the case of our 5-year-old children, also persisted several seconds afterwards. In contrast to the adult finding this increase, however, did not differ for communication type. A methodological difference between studies might explain these contrasting findings: In the study with adults, participants were asked to judge whether the utterance was meant as a request or not (Tromp et al., 2016). As this was the case for indirect requests and not for literal statements, pupil dilation here might also indicate arousal, memory capacity demands, attentional focus and the like. Moreover, making a metapragmatic judgment is inherently different from the pure processing of utterances for their comprehension (Ackerman, 1981; Bernicot et al., 2007). Since children in our study only had to comprehend the utterance for their object-choice, the taxing task of metapragmatic judgments was not required. The current pupil dilation data reveal that without this extra demand, the cognitive effort for processing indirect communicative acts is comparable to the effort for processing direct, literal statements.

The present study is a first step towards studying communication processing in children. Of course, one first study is not able to address this topic comprehensively, and

conclusions should be drawn carefully given limits in design and method. A possible limitation of this study is that we deliberately decoupled the utterance processing from the object choice phase. We did so in order to maximise the equality of non-essential factors (such as lightning, movement etc.) for the comparison of baseline and post-utterance (and post-choice) measures by using still frames. This may have compromised the naturalness of the situation. Future studies should test whether a more natural referential context in which children interpret utterances as they unfold results in different outcomes. Moreover, other stimuli and other tasks that do not force children to decide between two objects but rather consist of a more natural interaction between child and communication partner are required to validate the current results and theoretical implications. Finally, given that the ability to interpret indirect communicative acts seems to interact with children's concurrent language and cognitive development (Matthews et al., 2018), future studies might include a variety of measures regarding children's language abilities and cognitive development to investigate possible correlates of communication comprehension.

Conclusion

Figuring out what others want us to know or do from their indirect communicative acts is not a trivial task. For this we need to make inferences about the speaker's intentions. The present study shows that this is something even young children can do. However, to correctly choose the object intended by the speaker, children need to trust their gut feeling, i.e., their intuitive grasp of the speaker's intention processed in system 1. More elaborate consideration of what was said using system 2 capacities seems rather detrimental to children's object-choice. These findings support the idea that for successful communication it is necessary to process others' utterances on the fly in order to prepare the correct response quickly (Gisladdottir et al., 2018; Levinson, 2006). The present study shows that children are – in principle – ready to do so from age 3.

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Appendix

Overview of Context Scenarios, Object-Choice Options, Utterances by Condition and Correct Intended Objects of all Eight Trials.

Context	Available objects	Puppets' utterances		Intended object
		Direct communication	Indirect communication	
Breakfast	Cornflakes – Toast	I want the cornflakes. / I don't want the toast.	I do have a bowl. / I don't have jam.	Cornflakes
		I want the toast. / I don't want the cornflakes.	I do have jam. / I don't have a bowl.	Toast
Taking a walk	Scarf – Sun hat	I want the scarf. / I don't want the sun hat.	It's cold and wet outside. / It's not bright and warm outside.	Scarf
		I want the sun hat. / I don't want the scarf.	It's not cold and wet outside. / It's bright and warm outside.	Sun hat
Play time	Drum – Crayons	I want the drum. / I don't want the crayons.	I do have sticks. / I don't have a picture.	Drum
		I want the crayons. / I don't want the drum.	I do have a picture. / I don't have sticks.	Crayons
Snack time	Melon – Yoghurt pot	I want the melon. / I don't want the yoghurt.	The knife is clean. / The spoon is dirty.	Melon
		I want the yoghurt. / I don't want the melon.	The spoon is clean. / The knife is dirty.	Yoghurt
Play time	Paint brush – Board game	I want the paint brush. / I don't want the board game.	I do have a paint pot. / I don't have dice.	Paint brush
		I want the board game. / I don't want the paint brush.	I do have dice. / I don't have a paint pot.	Board game
Snack time	Juice – Cake	I want the juice. / I don't want the cake.	The cup is clean. / The plate is dirty.	Juice
		I want the cake. / I don't want the juice.	The plate is clean. / The cup is dirty.	Cake
Nursing pets	Rabbit – Dog	I want the rabbit. / I don't want the dog.	I have a carrot. / I don't have a leash.	Rabbit
		I want the dog. / I don't want the rabbit.	I have a leash. / I don't have a carrot.	Dog
Story time	Book – CD	I want the book. / I don't want the CD.	The story is not yet finished. / The CD player is broken.	Book
		I want the CD. / I don't want the book.	The CD player is intact. / The story is already finished.	CD

Overview of Data-Quality-Related Exclusion of trials and Remaining Number of Trials and Children for Analyses per Measure.

Measure	Trials excluded due to equipment failure	Number of remaining valid trials	Number of children in the analysis
Pupil dilation baseline	110	475	88
Pupil dilation post-utterance	125	460	89
Pupil dilation post-choice	108	477	89
PDDS	137	448	87
PD change before actual utterance	290*	295	87
PD change during actual utterance	292*	293	84
PD change after actual utterance	294*	291	83
Latency	89	496	98
Number of fixations	56	529	94
DLS	56	529	99

Note. The number of valid trials after reaction time criterion was 585 (in 105 children). *High

levels of excluded trials for pupil dilation during utterance measures can be explained by missing values for the baseline pupil dilation within the utterance stimulus trials.

PDDS: pupil-dilation difference score (mean difference between baseline pupil dilation and post-utterance pupil dilation), PD change: mean change in pupil dilation before, during, and after actual utterance within the utterance stimulus, DLS: differential looking score (score for how much of their overall looking time children spent on looking to the correct object).