Title
Communicative efficiency is present in young children and becomes more adult-like with age

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Abstract

Languages seem to be designed for efficient communication. For example, shorter forms are used for more predictable meanings, a tendency argued to stem from speakers' efficient language use. However, no study to date has systematically tested whether communicative efficiency shapes children's language use. Investigating whether such a pressure is already present in children will shed light on the development of children's' communicative behaviour and the respective roles of adults and children in shaping language structure. Here, we investigate the development of communicative efficiency using a novel experimental paradigm with children ages 4-10. Results show that communicative efficiency is attested already in young children and becomes more adult-like with age: as children grow, they are more likely to shorten messages (minimize effort) when a short message is sufficient for accurate communication. We discuss the implications of our results for cognitive development and for theories of language evolution and change.

Keywords: efficient communication; language development; language evolution

Introduction

One of the most striking commonalities across the world's languages is the tendency to assign less linguistic material to more predictable or frequent meanings (Gibson et al., 2019; Haspelmath, 2021; Levshina, 2021). For example, across languages, words that are used frequently tend to be shorter than words that are used rarely (Zipf, 1936); more predictable segments are more likely to undergo phonetic reduction than less predictable segments (Bell et al., 2009); and categories more frequently talked about receive shorter forms than categories that are less frequently talked about (e.g., present tense as opposed to past tense, Haspelmath, 2021). This association between form length and meaning is argued to derive from speakers' bias for efficient communication, reflecting the need to balance competing pressures (Grice, 1975; Jaeger & Buz, 2017; Levshina & Moran, 2021; Zipf, 1949). Speakers need to minimize production effort while maximizing understandability. An efficient trade-off between these two pressures involves producing less linguistic material whenever possible, e.g., when the meaning is predictable, and producing more linguistic material only when it is essential for being understood, e.g., when the meaning is unpredictable or when there is noise. Indeed, there is abundant evidence showing that speakers tend to reduce or omit elements when that does not compromise understandability, and tend to use longer forms when shortening or omitting them would impede understanding (Jaeger & Buz, 2017; Levshina & Moran, 2021). For example, when the same meaning can be expressed with a shorter or longer lexical form (e.g., *exam* vs. *examination*), speakers tend to use a shorter form in contexts where it is more predictable (Mahowald et al., 2013). A recent study directly tested the joint effect of both pressures using an artificial language learning experiment: when both minimization of effort and maximization of understandability were at play, participants produced a short form for a more frequent meaning, and a long form for a less frequent meaning (Kanwal et al., 2017).

Thus, there is growing evidence linking speakers' tendency to communicate efficiently and key features of language structure. However, virtually all of this evidence comes from adults. Investigating whether children are also communicatively efficient is important for several reasons. First, it can inform longstanding debates around who drives language change. While some theories argue that children drive change (Cournane, 2019; Hudson Kam & Newport, 2009), others claim that languages are shaped by adolescents and adults (e.g., Labov, 2007). Understanding which language users impose pressures for communicative efficiency can contribute to resolving this debate – for example, if children do not show a preference for efficient communication, that might suggest they are not responsible for at least those changes that improve communicative efficiency. Second, looking at communicative efficiency in children can shed light on the nature of this tendency, which is very salient in adults' language use. If the pressure for communicative efficiency is found from early on, then it may reflect a set of core cognitive dispositions, present in humans and less dependent of cognitive development or experience. By contrast, if this tendency emerges only in later ages, then it may rely on developmental processes or greater experience (with language use, or with the world).

Should we expect children to show the adult-like tendency for communicative efficiency? On the one hand, the tendency towards efficient use of language is claimed to operate during language acquisition (Fedzechkina et al., 2012; Fedzechkina & Jaeger, 2020; Kurumada & Grimm, 2019). Although the evidence for this comes from adult learners, the assumption is that the same should apply to children—who are, after all, the primary learners of language (though see Smith & Culbertson, 2020 and Tal & Arnon, 2020 for couner-evidence in adult and child learners respectively). On the other hand, there are reasons to think children might not show an adult-like tendency for efficient communication. Specifically, children might not exhibit the pressures of minimizing production effort and maximizing understandability, or they might balance them differently than adults. First, children might exhibit a weaker drive to maximize understandability: young children are notoriously bad at taking into account the perspective and knowledge of their interlocutors (Garrod & Clark, 1993; Glucksberg & Krauss, 1967; Kempe et al., 2018; Matthews et al., 2007; Nilsen & Graham, 2009). They could struggle with noticing there is comprehension difficulty and/or with adapting their speech to address it. Second, children may also have a weaker preference to minimize effort compared to adults, due their increased tendency for exploration despite of time and energy costs (Gopnik, 2020; Liquin & Gopnik, 2022).

Here, we investigate the developmental trajectory of communicative efficiency using a novel experimental paradigm. Children between the ages of 4 and 10 play a communication game, where they need to send signals to a simulated interlocutor in an environment that is sometimes noisy. As in real communication, longer signals are more effortful to produce but are more robust to noise. If efficient communication is present already in younger children, then longer messages should be used in the presence of noise and shorter messages in non-noisy environments, regardless of age. If, however, this tendency is tied to development, then the relation between noisiness and message length should vary with age. Finally, communicative efficiency might be present in young children, but to a weaker degree compared to adults. In that case, the relation between noisiness and message length should be present already in young children, but should increase with age.

The Experiment

In this study, we use a novel communication game to assess communicative efficiency in children of different ages. We investigate this tendency in non-linguistic communication to enable the creation of a task that is feasible for children as young as 4 years old. In this task, children communicate with a simulated interlocutor using visual icons: they have to tell the simulated interlocutor which action two characters should perform (kiss or hit). The design simulates effort and understandability in the following way. To simulate effort, messages can vary in length (1-3 icons), with longer messages taking more time to deliver than shorter messages. To simulate environmental noise, in some communicative turns messages are corrupted, and longer messages are robust to that corruption while shorter messages are not. We test whether message length varies with the presence of noise and whether this develops with age.

Participants

61 children participated in the experiment (age range: 4;3-

(A) **(B)**

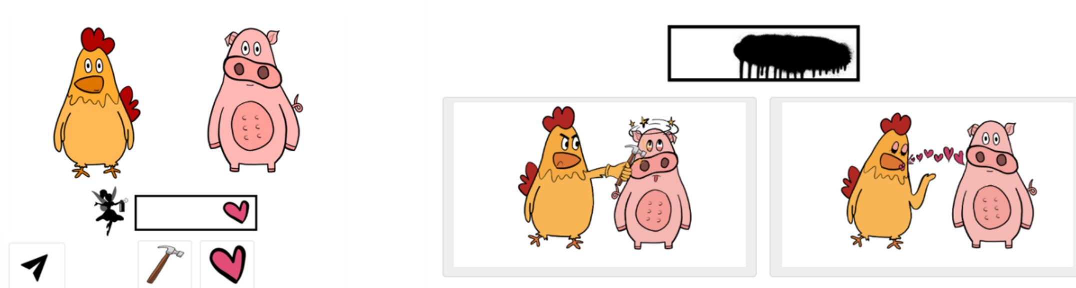

Figure 1: An example director trial. (A) After hearing an auditory prompt for the action, the participant creates a message to send to the computer. In this example, the computer's character—the chicken—should *kiss* the character they are about to meet—the pig. The fairy character appears next to the message, meaning the message will get sprayed. (B) The delivered message is displayed above the two possible actions. In this example, the message shows only black spray because the fairy appeared, and the original message was only 1-icon long.

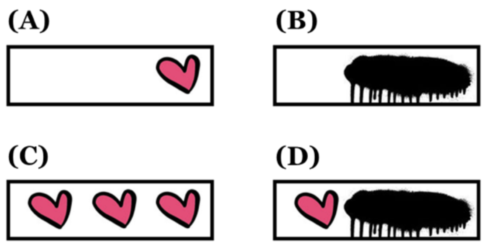

Figure 2: Example message types conveying the *kiss* action. Note that the noise obscures the first two icons when being "read" from right to left, as in Hebrew (participants' native language). (A) A 1-icon length message, without noise. (B) A 1- or 2-icon length message, with noise. (C) A 3-icon length message without noise. (D) A 3-icon length message with noise.

9;11y, mean age: 6;10y). All children were visitors at the Bloomfield Science Museum in Jerusalem. They were recruited for this study as part of their visit to the Israeli Living Lab in exchange for a small reward. Parental consent was obtained for all children. All children were native Hebrew speakers, and none of them had known language or learning disabilities.

Design and materials

The communication game involved hearing a cue for an action, and then creating a message to convey to the other player which of the two actions they should perform when meeting one of the other characters. The actions were kissing and hitting, cued by a kissing sound or a boing sound respectively. Each trial featured two characters selected from the set *chicken, pig, dog, cat, cow*. The agent was always the character of the player who received the message (the child or the computer, as described in the Procedure section below), and the patient one of the three remaining characters. That is, both players knew who the agent and who the patient was, and only had to choose the correct action. The messages could include either a heart icon (indicating the kissing action) or a hammer icon (indicating a hitting action). A given message could contain a minimum of one icon, and a maximum of three icons. Example stimuli are shown in Figure 1, and example messages in Figure 2.

To simulate probabilistic noise in the environment, the game included a naughty fairy with a can of black spray paint. Whenever she appeared she sprayed the messages before they got to the partner, "dirtying" them in the following way: if the original message contained three icons then the third one remained visible, but if the original message contained less than three icons then no icon remained visible (see Figure 2).

Procedure

The experiment was coded in javascript using jsPsych (De Leeuw, 2015). Children sat with headphones in front of an iPad, next to a research assistant that provided them with verbal instructions. They were told that they were going to play a communication game with a cartoon character. As a first step, participants were presented with 5 animal cartoon characters and were instructed to choose one of them as their character in the game. Next the computer chose a character for itself (randomly chosen from one of the remaining four characters). Children were told that the goal of this game was to accumulate as much treasure as possible together with the other character.

For each trial in the experiment, the child was either the director or the matcher. In director trials, children heard a sound cuing the correct action for this trial (either a kissing sound or a boing sound indicating hitting with a rubber mallet). They were instructed to create a message to convey to the other player what action that player's character should take (i.e., should the computer's character kiss or hit the character they are about to meet). To create a message, an empty rectangle appeared on the screen, with three icons beneath it: a heart, a hammer and a "send" icon (see Figure 1A). A kissing action was conveyed by clicking the heart icon, and a hitting action by clicking on the hammer icon. Importantly, the message could either contain one icon, two or three icons (see Figure 2). The longer messages were, the longer it took to create them: every icon click was followed by a 3-seconds interval during which no further action could be made. Participants sent the completed message by clicking the "send" icon. Messages could not be longer than 3 icons (after 3 icons were clicked the only option was to click the "send" icon).

After the participant sent a message, that message was shown above the two possible actions for the trial (e.g., *chicken giving a kiss to pig* vs. *chicken giving a boing to pig*, see Figure 1B) and the computer made a choice. If the message delivered had no visible icons (i.e., because the naughty fairy appeared and the message sent was shorter than 3 icons, as in Figures 1 and 2B), or if the visible icons were contradictory (i.e., containing both a heart and a hammer), then the computer chose the wrong action. Otherwise, the computer chose the action indicated by the message sent. A correct choice resulted in the chosen action marked in green, as well as a cartoonish success sound and a drawing of accumulated gold. An incorrect choice resulted in the chosen action marked in red and a cartoonish sound of a failure.

In matcher trials, children received a message from the computer, describing whether the action was kiss or hit. As with director trials, the messages received could be of different lengths, and could be obscured by the naughty fairy's spray or not. The messages never contained a mix of hearts and hammers, and visible icons were always for the correct message. The sent message was shown above the two possible actions, and the participant had to choose between them. Feedback was given in the same way as in director trials.

Before the start of the game, the experimenter explained the task and demonstrated two successful director trials. In the first demonstration, the experimenter created a message composed of only one heart, in the second one the message was composed of three hearts. The experimenter emphasized that the latter message takes more time to create. Then, the

Table 1: Regression model for matcher trials

	Estimate	**Std. Error**	**z -value**	***p*-value**
(Intercept)	0.013	0.14	0.094	0.925
Age (centered)	-0.012	0.085	-0.143	0.887
Understandability = understandable	3.915	0.402	9.733	**<0.0001 *****
Trial number	0.022	0.012	1.769	0.077 **.**
Age * Understandability = understandable	0.59	0.2	2.945	**0.003 ****

experimenter explained that a fairy was sometimes around, and when she appeared, she sprayed the messages. The participants were told that luckily, they could see when the fairy is around: they would see her lurking next to the message they were creating (see Figure 1). Participants were told they should pay close attention to whether the fairy is around so that they could be careful of her.

After this explanation and demonstration, the actual communication game started. There were 32 trials, 16 director trials and 16 matcher trials. The fairy appeared randomly in half of the director trials and half of the matcher trials (except for the first director trial, which always had a fairy). In matcher trials, children only saw the outcome of the fairy's appearance—a dirty message. In half of these trials (4) the message only contained black spray (as in Figure 2B), suggesting that the original message was shorter than 3 icons, and in half (4) the trials, the message had black spray and one visible icon (as in figure 2D), suggesting that the original message was 3-icons long. In non-noisy trials (i.e., when the fairy did not appear) half of trials (4) had messages that were 3-icons long and half (4) had messages that were 1-icon long. The correct action (kiss vs. hit) was counterbalanced across trials. The agent was always the character of the player (child or computer) who received the message; the patient was randomly chosen from one of the remaining three characters.

During the game, participants made decisions and clicked on the icons by themselves without the help of the experimenter. However, the experimenter made sure that participants noticed the fairy: throughout the game, the experimenter noted out loud whenever the fairy appeared ("oh, watch out, the fairy is here"). When the messages sent by the participant were completely obscured by the fairy (i.e., in noisy trails where participants have sent short messages, as in Figure 2B) the experimenter would say "oh, it got completely dirty. Now the computer will just have to guess what to do". In matcher trials, in cases where the messages received by the child were completely obscured, the experimenter would say "oh, the message is completely dirty. Now you will have to guess what to do". These comments were included to make sure that children's behaviour could not result from misunderstanding the game.

Results

To ensure children understood the game, we first analysed the matcher trials, to see whether participants chose the correct action based on the computer's descriptions. Crucially, participants could only correctly identify the correct action in trials where the message had visible icons (i.e., trials where the fairy did not spray the message, or trials where the delivered messages were dirty but were long enough to have one visible icon, as in Figure 2A, 2C and 2D). Each participant had 8 such "understandable" trials and 4 "non-understandable" (i.e., trials without visible icons as in Figure 2B). We used a mixed-effect logistic regression model to examine the effect of understandability of the received message on choice of the correct action (all further models reported here were run using the glmer function in R, Bates et al., 2015, and the maximum random effect structure justified by the data that converged, Barr et al., 2013). The model included fixed effects for trial number as a centered continuous variable, message type (understandable vs. non-understandable, treatment coded with non-understandable as the baseline), age as a centered continuous variable, and the interaction of age and message type. The model also included by-participant slopes for message type and random intercepts for participants (see Table 1 for full model). Children's accuracy was much higher in understandable compared to non-understandable trials (95% vs. 50%, β=3.92, SE=0.4, p<.0001). Accuracy in non-understandable trials did not differ from chance (β=0.013, SE=0.14, p=0.9). There was an interaction between age and message type, such that accuracy increased with age in the understandable messages (β=0.59, SE=0.2, p=.003). These results suggest that children of all ages understood the task and were able to interpret messages.

We next analysed the director trials, to test the key question of interest. Trials in which the received message contained the wrong verb (i.e., a hammer when the correct action was kissing) were excluded from analysis (n=12, remaining n=964 trials). Figure 3 shows the proportion of long messages (3-icons messages) as a function of age and noise (i.e., presence of the fairy). A mixed-effect logistic regression model was run, predicting message length (3-icons messages vs. 1-icon messages)[1] from trial number as a centered

[1] The pattern of results remains the same when treating message length as a continuous variable (between 1-3 icons).

Table 2: Regression model for director trials

	Estimate	Std. Error	z -value	*p*-value
(Intercept)	2.117	0.293	7.225	**<0.0001 *** **
Age (centered)	0.16	0.162	0.989	0.323
noisiness = not noisy	-5.723	0.928	-6.169	**<0.0001 *** **
Trial number	0.046	0.012	3.756	**<0.0001 *** **
Age * noisiness = not noisy	-2.052	0.544	-3.77	**<0.0001 *** **

continuous variable, trial type (noisy vs. not noisy, treatment coded with noisy as the baseline), age as a centered continuous variable, and the interaction of age and trial type. The model also included by-participant slopes for noisiness and random intercepts for participants (see Table 2 for full model).

Results reveal that message length increased with trial number (β=0.05, SE=0.12, *p*<.0001), suggesting that the need to create longer messages was learned throughout the experiment. Importantly, children conditioned message length on noisiness: they used shorter messages for non-noisy trials compared to noisy trials (β=-5.72, SE=0.93, *p*<.0001), illustrating communicative efficient choices. Finally, we also found an interaction, such that the tendency to use shorter messages for non-noisy trials increased with age (β=-2.05, SE=0.54, *p*<.0001). That is, the older children were, the more likely they were to use shorter messages in non-noisy trials. This suggests that children become more communicatively efficient with age. It could be that young children simply enjoy clicking on icons more than older children, regardless of trial type. To make sure young children were not oblivious to noisiness, we ran an identical regression with age as a categorical variable binned to three age groups (ages 4-6, 6-8, 8-10, treatment coded with the youngest age group as the baseline level). That is, the simple effect of noisiness in this model reflects whether the effect is present for the youngest age group. This model did not include by-participant slopes for noisiness since it did not converge. We found a simple main effect of noisiness, suggesting that even at the youngest age group (4-6 years old) messages in non-noisy trials were shorter than messages in noisy trials (β=-1.58, SE=0.3, *p*<.0001).

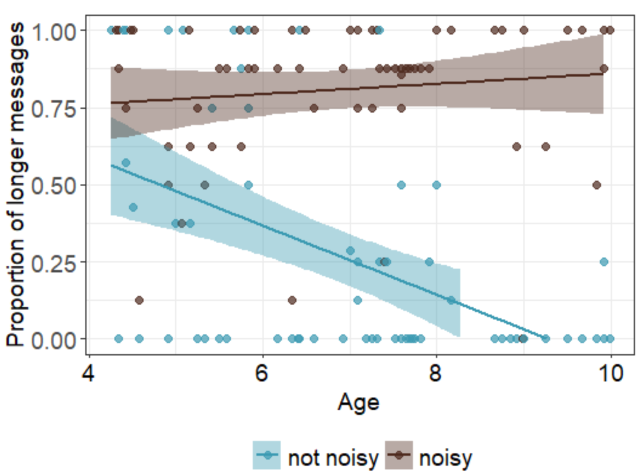

Figure 3: Proportion of longer messages as function of age (in years) and noise. Individual points represent by-participant means. Solid lines show estimated regression lines for noisy and not noisy trials, along with 95% confidence intervals.

Discussion

A bias for communicative efficiency in language users has been argued to have widespread implications for language structure (Gibson et al., 2019; Levshina & Moran, 2021). This bias has been argued to be at play both in language learning and in language use (e.g., Fedzechkina et al., 2012). However, the evidence for it comes almost exclusively from adults. The current study explored whether there is evidence that a pressure for communicative efficiency is already present in young children, or whether it emerges only at a later age. To this end, we created a novel child-friendly communication game, where signals are sent to a simulated interlocutor in an environment that is sometimes noisy. As in real communication, longer signals are more effortful but are more robust to noise. Our results suggest that communicative efficiency is already present in young children, and that it develops with age: while the youngest children show evidence of conditioning message length on the presence of noise, this effect increases dramatically with age.

Importantly, efficiency could develop with age in two ways: a developmental increase in the tendency to use *longer* messages in noisy environments, or a developmental increase in the tendency to use *shorter* messages in non-noisy environments. The former would point to an increase in the pressure to maximize understandability, whereas the latter would reflect an increase in the pressure to minimize effort. Our findings support the latter. That is, older children differ from younger children in being more likely to use shorter messages in non-noisy environments.

Why would the pressure to minimize effort increase with age? Compared to older children and adults, young children are more willing to be creative, spend more time exploring, and are less driven by simple heuristic solutions (Hart et al., 2022; Liquin & Gopnik, 2022). These tendencies could make even effortful activities more rewarding for younger children, leading them to exert more effort even when it is not, strictly-speaking, necessary. Importantly, the pressure to maximize understandability may also develop with age. In particular, young children are typically bad at modifying their messages according to their interlocutor's knowledge (Garrod & Clark, 1993; Glucksberg & Krauss, 1967; Kempe et al., 2018; Köymen et al., 2014; Matthews et al., 2007; Nilsen & Graham, 2009). That we did not see such an effect here may be driven by the design of the study: whenever the messages were non-understandable (because the fairy had obscured a short message) experimenters made it explicitly clear for children that the messages were in fact non-understandable, and that the correct action could only be guessed. This explicit instruction was introduced in order to make sure young children's performance in the task could not be attributed to any misunderstanding of the communicative setting. However, these explicit explanations may have leveled out any possible differences between the ability of younger and older children to infer what their interlocutor could know. In future studies we plan to directly test this, as well as to investigate the effect of different sources of noise on children's communicative efficiency.

Importantly, our experiment involved non-linguistic communication. While we manipulated production effort in a similar fashion to what has been done in parallel artificial language learning experiments (Fedzechkina & Jaeger, 2020; Kanwal et al., 2017), it is of course possible that we would see a different pattern of results in an experiment featuring a more linguistic mode of communication (e.g. featuring novel words rather than iconic symbols).

Finally, our findings have implications for understanding the role of children in driving processes of language evolution and change. If as our results suggest, young children show a weaker tendency for efficient communication than adults, then this particular feature of language might be driven more by adult language users (Labov, 2007). Importantly, children's role in language change is typically attributed to learning (Cournane, 2019; Hudson Kam & Newport, 2009). Children might therefore still be the agents driving other types of language change (e.g., Culbertson & Newport, 2015, 2017).

To summarise, we investigated the developmental trajectory of efficient communication. We found that children were more likely to use shorter messages in non-noisy environments the older they were. This suggests that the tendency for communicative efficiency is attested in young children and develops with age. This study is an important first step in understanding the nature and origin of communicative efficiency in humans. More generally, our findings underscore the need to investigate the development of cognitive biases and mechanisms argued to shape language.

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