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Young children are natural pedagogues

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ABSTRACT

Young children are sensitive to ostensive cues (OC), a specific set of communication signals which denote a learning context. This endows human communication with a protocol – termed *natural pedagogy* – adapted to transmit knowledge. It remains unknown whether children spontaneously communicate in this protocol. Here, we show that children display a broad repertoire of ostensive signals during pedagogically relevant moments of their discourse. We introduce an experimental setup where an adult actor plays erroneously a simple inference game which the child has previously learned how to play. This naturally shifts the child from a student to a teacher's role in the educational dialog. In Study 1 ($n = 31$), we examine children's use of ostensive cues and gestures as they develop their explanations (3–5 and 6–8-years old). We demonstrate that all children use non-verbal behaviors specifically during moments of pedagogical relevance and the dynamics' use of ostensive signals change through childhood. In Study 2 ($n = 16$),

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the adult pupil minimizes all reception to non-linguistic OC and gestures. This resulted in a decrease of children's frequency of OC during pedagogical episodes but did not affect other gesturing behavior. In Study 3 ($n = 15$) we show that decreasing ostension during children's history of instruction does not decrease their own ostension while teaching. This rejects the hypothesis that children teach by simple imitation of their learning experience and showed instead, that they can diagnose the sources of the adult pupil's failure and adjust their own teaching accordingly. Together, these results demonstrate that children are spontaneously tuned in the emitter side of natural pedagogy.

1. Introduction

Teaching by definition involves two parties, a teacher and a pupil, who modify their behaviors in order to achieve a meaningful transmission of knowledge. This interaction constitutes the minimal core of pedagogy. While neuroscience and cognitive neuroscience have led to a thorough understanding of how we learn, we remain quite ignorant on the cognitive mechanisms of how we teach (Caro & Hauser, 1992; Davis-Unger & Carlson, 2008a, 2008b; Strauss & Ziv, 2012; Strauss, 2005; Thornton & Raihani, 2008). Paradoxically, teaching constitutes the most prominent and distinctive vehicle to propagate knowledge in human societies (Csibra & Gergely, 2011; Tomasello & Rakoczy, 2003), and has had a major impact on cementing our culture (Csibra & Gergely, 2011; Posner & Rothbart, 1998; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Tomasello & Rakoczy, 2003).

Only recently have we begun to understand how teaching develops through life. A handful of studies showed that children spontaneously teach when they sense a disparity of knowledge (Maynard, 2002; Strauss & Ziv, 2012; Ziv & Frye, 2004; Ziv, Solomon, & Frye, 2008). It has also been shown that the exchange of knowledge between children is initially marked by guidance, with the child teacher regulating the experience and later on becoming a more collaborative behavior (LeBlanc & Bearison, 2004). How and when children engage in teaching was studied in the remarkable seminal work of Strauss and collaborators (Strauss & Ziv, 2012; Ziv & Frye, 2004; Ziv et al., 2008). The authors showed that children as young as age 3 teach effortlessly and spontaneously. In these first manifestations of teaching children rely mainly on demonstrative strategies. Five year old children accompany demonstrations with more elaborate explanations, including feedback behaviors and errors diagnosis (Strauss, Ziv, & Stein, 2002). Accordingly, Strauss and others proposed that teaching is a natural cognitive ability (TNCA) acquired at an early age without any apparent instruction (Strauss, 2005, 2012; Strauss & Ziv, 2012; Strauss et al., 2002). One natural question derives from this observation and is addressed in the present paper: Are young children natural teachers? i.e., can they communicate information efficiently?

This question can be addressed by quantifying the precision of verbal explanations (LeBlanc & Bearison, 2004; Ziv & Frye, 2004; Ziv et al., 2008). In fact, several researchers (Fuchs et al., 1996; Graesser, Person, & Magliano, 1995; Topping, Cambell, Douglas, & Smith, 2003) have defined normative procedures to identify fragments in discourse that have a clear pedagogical intention. These pedagogical episodes were defined according to the conventional definition of 'pedagogy' as explicit communication of information in terms of knowledge content of another individual (Csibra & Gergely, 2006; Roscoe & Chi, 2007). Pedagogical episodes included different behaviors (Fuchs et al., 1996; Graesser et al., 1995; Topping et al., 2003) such as helping behaviors, anchoring learning in specific examples, question answering and explanatory reasoning, amongst others. However, the precision of verbal explanations is severely confounded by language fluency, temperament and attention (Schulz & Gopnik, 2004; Steels, 2006). Hence, a more precise and uncontaminated way to probe teaching efficiency in children is necessary in order to address this question properly.

Some aspects of human communication rely on an implicit communication protocol (Csibra, 2010). The work by Csibra, Gergely, and collaborators demonstrated that learning in children changes fundamentally when demonstrations are accompanied by ostensive behaviors (Gergely, Egyed, & Király, 2007; Southgate, Chevallier, & Csibra, 2009; Yoon, Johnson, & Csibra, 2008). Ostensive cues (OC), which are signaled by a broad set of non-verbal behaviors (gaze, change in tone of voice, body positioning, among others), act as prosodic markers providing emphasis to relevant (and general) items of discourse (Csibra, 2010; Csibra & Gergely, 2006). From these findings, Csibra and Gergely developed the theory of *natural pedagogy* (NP), which postulates that children naturally understand, as receivers of information, that ostension is an indicator of pedagogical pertinence. They argue that NP constitutes a theory of pedagogy because the implicit communication protocol allows the transfer of generic and generalizable knowledge to young children (Csibra & Gergely, 2009). Strauss, Calero, and Sigman noted that NP has studied only one side of pedagogy, evaluating how and when very young infants are tuned at the receiver side of this communication protocol (Gergely et al., 2007; Strauss, Calero, & Sigman, 2014). To reiterate, in the present study, we are studying the second, emitter, side of this communication, i.e. the teaching side.

Natural pedagogy constitutes a theory to explain ostensive signaling in pedagogy. However, there are many other non-verbal behaviors that are not ostensive but nonetheless have clear pedagogical importance. The clearest examples are gestures (Goldin-Meadow, 2002; Skipper, Goldin-Meadow, Nusbaum, & Small, 2007; Willems & Hagoort, 2007). Children spontaneously produce gestures early in life and it has been shown that encouraging them to use gestures brings out implicit knowledge and leads to learning (Broaders, Wagner Cook, Mitchell, & Goldin-Meadow, 2007; Göksun, Hirsh-Pasek, & Michnick Golinkoff, 2009; Goldin-Meadow, Wagner Cook, & Mitchell, 2009). Furthermore, children convey relevant information with their gestures that cannot be found in their speech (Goldin-Meadow & Sandhofer, 1999). Therefore, if teaching becomes more sophisticated with age, as Strauss and others postulated, and gestures accompany the discourse along with OC, then children must learn to combine the different kinds of non-verbal communication within the discourse in order to become teachers. In the present work, we restrict our gesture analysis to Referential Signals (RS) (see Materials and Procedures), which are not considered OC but have been shown to be a crucial source of information during communication (Gliga & Csibra, 2009). RS are spontaneous gestures generated by the speaker during a discourse and do not form a linguistic system; instead they support a message that has linguistic structure (Goldin-Meadow, 2002; Goldin-Meadow & Wagner Alibali, 2013).

2. Study 1

The main goal of the present work is to study whether children are spontaneously tuned at the emitter side of natural pedagogy. As a consequence, in Study 1 we examined the development of children's use of non-verbal communication when conveying relevant information, i.e. when teaching.

As we mention above, the use of OC in children has been examined regarding receiving pedagogy but so far; it has been neglected the study of these signals' role during children's production of generic and generalizable knowledge. Here, we aim to understand (1) whether OC are being used when children engage in a teaching episode, and if they do; (2) how is the timing and frequency of utilization of OC and, what kind of signals are being employed during the discourse. Therefore, we seek to investigate whether children teach, capitalizing on the inborn sensitivities of the receiver, by transferring knowledge ostensively in a manner which signals pedagogical relevance. The simplest way to achieve this behavior by the child is simply to boost ostension throughout the extent of a discourse with pedagogical relevance. We called these moments "*pedagogical episodes*"-. On the other hand, a subtler and more economical manner to use OC would be to precisely time and coordinate sparse ostensive signals locked to the onset and offset of pedagogical episodes. Based on this reasoning we examine the following hypotheses (H); (*H1*) Ostensive cues increase during pedagogical episodes and, (*H2*) Ostensive cues are timely locked to indicate the temporal borders (onset and offset) of pedagogical episodes. By studying the timing of occurrence of OC we will be able to characterize what kinds, how many and the distributions of these non-verbal signals when children teach.

Furthermore, as discussed in the general introduction, TNCA proposes that teaching is ubiquitously found at early ages and evolves though development, from proto-teaching to a more complex activity.

Consequently, we hypothesize also that; (*H3*) the distribution of ostension (how it is specifically allocated and distributed within pedagogical episodes) changes throughout development and (*H4*) children employ alternatively different channels of non-verbal communication (OC and RS) during the pedagogical episodes.

2.1. Material and methods

2.1.1. Participants

A total of 31 children participated in Study 1. The sample included $n = 13$ preschoolers (6 boys and 7 girls) ranging in age from 3 years and 3 months to 5 years and 6 months; $M = 4$ years and 7 months; $n = 18$ first and second graders (9 boys and 9 girls) ranging in age from 6 years and 1 month to 8 years and 7 months; $M = 7$ years and 2 months. Studies were conducted in a school in Buenos Aires. All children's parents or legal guardians gave signed voluntary consent.

The consent form, presented to the caregivers was previously authorized by an Ethical Committee; (*Comité de Ética de la Dirección de Investigación del Centro de Educación Médica e Investigación Clínica "Norberto Quirno"* (CEMIC), Unidad Asociada del CONICET (Protocolo N° 683)).

2.1.2. Experimental design

Children were brought into a game room and sat in a small chair 90° from the experimenters, facing a hidden camera (Bloggie Sony TS20). In different phases of Study 1 children interacted with two adult experimenters: one played the role of the child's adult teacher, henceforth referred to as the *adult teacher* and the other play the child's adult pupil, henceforth referred to as the *adult pupil*. Before beginning the study the children interacted with both experimenters until they felt comfortable and know them well by their given name. At all times, when talking to the children, the adult teacher referred to the adult pupil by his or her given name (and similarly the adult pupil to the adult teacher) and they never referred to each other by their roles.

The study had four different phases: (1) *Instruction* (I): The study began with a phase in which the adult teacher gave instructions on how to play a simple inference game based on (Schulz & Gopnik, 2004). Briefly, the adult teacher showed the child a monkey puppet, a glass vase and two plastic flowers lying on the table. The vase, the monkey and the flowers on the table were always put the same position. Whenever they were moved (for instance when the monkey smelled a flower) they were then returned to their original position. The adult teacher tells the child: "*Monkey likes to smell flowers, but some flowers make Monkey sneeze. Will you help me figure out which flower makes Monkey sneeze?*". (2) *Child played for the first time* (CP1): Children played the game with the adult teacher. The adult teacher first put a flower in the vase and then had the monkey puppet approach to smell it. Then she or he had the monkey back away, put the other flower in the vase and had the monkey approach again to smell it. Only one of the two flowers made the monkey sneeze. The order of smelling the sneeze-producing or non-sneeze-producing flower was varied randomly. This procedure was repeated three times. Then, the teacher placed both flowers on the vase and brought over the monkey who always sneezed, repeating this procedure three times. After this display, the adult teacher put both flowers on the table and asked the child which flower made the monkey sneeze. All participants in this study responded correctly to this question. The adult teacher gave feedback by clapping, smiling and saying: "Muy bien!" ("Very good!"); (3) *Adult Pupil plays for the first time* (AP1): The adult pupil entered the room, and the adult teacher then told the child that they were now going to play with him. The adult teacher played with the adult pupil in the same procedure as described above in (2) with the exception that the color of the flowers was changed. The child observed, sitting at the same table. When asked to indicate which flower makes the monkey sneeze, the adult pupil always responded incorrectly by choosing the wrong flower. The adult teacher gave feedback to the adult pupil saying, though without much emphasis, that the answer was wrong. The adult teacher then asked the child if he or she wanted to play again (all the children said yes) and left the room to look for more flowers. The flowers and the monkey were taken by the adult teacher; to make it more likely that the child will use OC and gestures to convey information. Only the vase remained on the table to serve as a reference point. (4) *Teaching* (T, T-phase): The adult pupil asked the child three questions: "How did I play? Did I choose the right flower?" and "Could you show me how to do it, how to play? After the child finishes elaborating his/her spontaneous response (without any interference or interruption) the adult pupil asked: "Is there something else you want to tell me?" When the child finished his or her explanation, the adult teacher entered the room again.

2.1.3. Coding

We analyzed the videos based on a pre-defined list of relevant features, *events*, indexing ostensive cues, referential signals and pedagogical intention. Videos were analyzed independently by two researchers with extensive training. One of the analyses was conducted by the author (CIC) and the other by a research assistant who was completely blind to all aspects of the Study. A third researcher analyzed the similarities and differences between both codes. Two children were selected at random and both researchers' codifications from the videotape were compared. The mean percent agreement for all the measures was 99% and showed only a very small difference (very rarely greater than 0.5 seconds) in the onset and offset of the events. The mean Cohen's kappa for all the measures was 0.96.

Coding was based on the following guidelines:

Measurements of ostensive cues made by the child: (1) Spontaneous eye contact to the experimenter. Eye contact is an ostensive signal in humans and carries a positive value (Csibra, 2010; Kleinke, 1986). It is a signal that unambiguously specifies its target and establishes a communicative link between two people. Eye contact quantified in this section included those in which the child spontaneously looks at the experimenter, not as a result of an inquiry. Each eye contact the child made was coded when it occurred and in relation to which experimenter, adult pupil or teacher; (2) Contingent Reactivity, the degree of engagement, was evaluated as a repertoire of voluntary movements and facial expressions and then measured as high, intermediate and low (Csibra, 2010). Faces of people are highly salient to young infants and convey information for social interactions (Bahrick, Lickliter, & Castellanos, 2013); (3) Spontaneous non-specific gestures which are idiosyncratic for each child (moving the hands and nodding the head). These types of gestures tend to have the same form regardless of the content of information. They accompany the discourse but do not convey significance (Goldin-Meadow & Sandhofer, 1999); (4) Changes in the body orientation directed toward the adult pupil. Positioning in front of the recipient establishes a direct link (Csibra, 2010). Each time the child changed his/her body orientation this was coded; (5) Calling the experimenter by his or her name. The infant's own name is an ostensive signal itself and is the earliest word infants can recognize around 4.5 months of age (Gergely et al., 2007; Mandel, Jusczyk, & Pisoni, 1995; Newman, 2005). Together with eye contact, calling the child by his/her name in motherese is the first OC that helps them to recognize the presence of a communicative intention (Csibra, 2010). Given its importance we quantified if the children used the experimenter's name during teaching; (6) Eye-brow raising is another facial signal that is interpreted as ostensive stimuli in adults and for this reason was evaluated in the children's use (Csibra & Gergely, 2009). Each instance of eye-brow raising the child made was coded when it occurred.

Measurements of referential signals (RS): are gestures that reveal implicit knowledge and contain substantive information that listeners can extract. (1) Deictic gestures. They refer to elements in the conversation even when the elements are not present, such as pointing, looking or hand movements, referring to objects by their current or previous spatial locations. (2) Iconic gestures. These capture semantic aspects of the discourse's content (Goldin-Meadow & Wagner Alibali, 2013; McNeill, 1992). RS that were quantified included pointing or looking to specific locations in the table – such as the position of the monkey, where it was seated during the game, the vase or the flowers – and imitating the particular movements of the monkey toward the flowers or the experimenter putting the flowers in the vase. Each RS was coded when it occurred.

Measurements of pedagogical intention: Pedagogical episodes were quantified only during the T-phase according to conventional definitions of 'pedagogy' as explicit communication of information in terms of knowledge content of another individual (Csibra & Gergely, 2006; Roscoe & Chi, 2007). Pedagogical episodes included different helping behaviors (Fuchs et al., 1996; Graesser et al., 1995; Topping et al., 2003) such as anchored learning in specific examples and cases ("If the blue flower makes Monkey sneeze, then choose the blue one"), collaborative problem solving and question answering ("I will help you, what you should do is this. . ."), deep explanatory reasoning ("If one flower makes

Monkey sneeze, then the other will not"), feedback, error diagnosis, and remediation ("You made a mistake before because you choose the flower that did not make Monkey sneeze. Next time, choose the other one!").

Non-pedagogical episodes were defined as communicative acts that were also related to the game during the child's discourse. Even when the statement may seem that it had a pedagogical intent, (for example, "You should've paid attention during the game"), the phases were considered unhelpful because there was no real information about how to choose the right flower. The following sentences constitute typical examples of non-pedagogical episodes; "This game is easy"; "I won"; "I chose the correct flower" or "You should've paid attention during the game".

2.1.4. Event-locked analysis

In order to understand the dynamics of different events during pedagogical episodes, we study whether these events (pre-defined elements from a list of features that was utilized during the coding) are aligned to each other. For this, we compute an average event-lock as described in what follows; first, we select a pair of events (or groups of events) between which the relative time-locking is to be evaluated. In this pair, one event serves as a reference ($\mathbf{ev_R}$) to which the other ($\mathbf{ev_A}$) will be aligned. For example, in Fig. 1c $\boldsymbol{ev_R}$ corresponds to the event *pedagogical episode* and $\mathbf{ev_A}$ corresponds to the event eye contact. For each subject, we codified the time $\boldsymbol{T_i}$ of occurrence of each event $\boldsymbol{ev_R}^{\mathbf{i}}$. $\boldsymbol{T_i}$ can be either the onset or offset of $\boldsymbol{ev_R}^{\mathbf{i}}$. For each subject $\boldsymbol{s}$ we populated a binary matrix $\mathbf{vs}(\boldsymbol{i,t})$ such that $\mathbf{vs}(\boldsymbol{i,t}) = 1$ if ev_A was true at $\boldsymbol{T_i} + t$ and $\mathbf{vs}\ (\boldsymbol{i,t})$ = otherwise. After averaging (first across events $\boldsymbol{i}$ and then across subjects $\boldsymbol{s}$) we obtain a time varying signal $\boldsymbol{v(t)}$ which measure the degree of time-locking of $\mathbf{ev_A}$ to $\boldsymbol{ev_R}$. To determine the significance of this alignment $\boldsymbol{v(t)}$ was compared to the event-locked average $\boldsymbol{v_{indep}(t)}$ that would result if both events were fully independent. We approximated $\boldsymbol{v_{indep}(t)}$ by randomly shuffling the ime of occurrence of the $\mathbf{ev_A}$ events; the random shuffle procedure was repeated 100 times and $\boldsymbol{v_{indep}(t)}$ was defined as the average of these randomization. Note that $\boldsymbol{v_{indep}(t)}$ is not constant across time (as can be seen in the blue curves of Figs. 1c and 2b and c) since the probability of being outside the teaching phase increases further away from time zero. Given a time interval of interest a *t*-test was used to determined whether $\boldsymbol{v(t)}$ was significantly different from $\boldsymbol{v_{indep}(t)}$.

2.2. Results

2.2.1. Are children tuned in the emitter side of the natural pedagogy protocol?

To examine our first hypothesis (*H1*), for each phase in Study 1, we measure the density of all OC (spontaneous eye contact, directing body orientation, contingent reactivity and eye-brow raising, coded as describe in Materials and procedures). As is shown in Fig. 1a, children were grouped as 3–5 years old (preschoolers–young children) and 6–8 years old (first and second graders–older children). For both age ranges, we observed a significant almost 5-fold increase in OCs during the T-phase relative to all other phases (Young children $F(3, 44) = 85.710$, $p = 0.0064$ and Older children $F(3, 48) = 15.230$, $p = 0.0083$). This result suggests that children used the OC distinctively when they engage in teaching.

However, the T-phase is the only one in which children are asked to speak. It is then necessary to eliminate the possibility that the observed increase in OC effects results merely from changes during conversation compared to playing or observation. To further investigate whether there is a specific effect of pedagogy on children ostension, we parsed children's discourse within the T-phase in *pedagogical episodes* (Strauss et al., 2002) and fragments of the discourse which do not convey pedagogical intention[2] (*non-pedagogical episodes*) (see Materials and Methods).

This classification of discourse allowed us to make an analysis of how OC are distributed within the T-phase in temporal alignment with moments of the dialog which are pertinent to pedagogy. Since

[2] Another possible approach to investigate the specific role of pedagogy in ostension is to generate a control condition in which children talk about something for which they are equally motivated to communicate but which has no pedagogical intention. For instance, one may ask the child to tell the adult pupil about a movie he has seen, or about a friend, or about any story he likes. However, it is very difficult (probably impossible) to assure that the children are not engaged in a pedagogic activity when communicating such material and as a consequence we considered more adequate to parse discourse in events of pedagogic and non-pedagogic content.

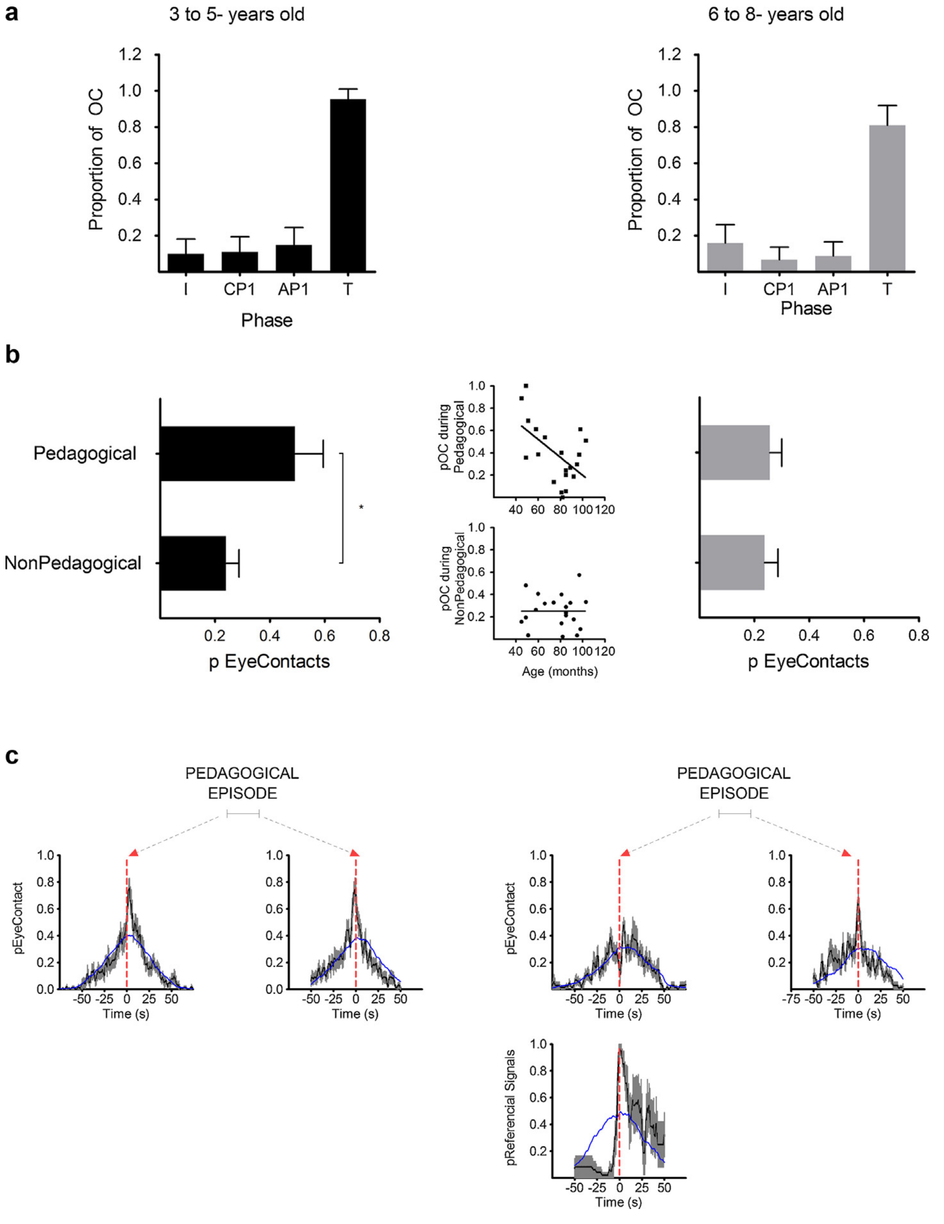

Fig. 1. Ostension during teaching for younger and older children. (a) Proportion of time using ostensive cues (OC) during the different stages for 3–5 and 6–8 years old, left and right panel, respectively) All data is presented as *M* and *SD*. (b) Densities of eye contact for pedagogical and non-pedagogical episodes during the T-phase for 3–5 and 6–8 years old, left and right panel, respectively and middle panel, pedagogical (black squares) and non-pedagogical (black dots) episodes for each child as a function of age. (c) Top: alignment of probability of eye contact with the adult pupil and pedagogical episodes during the T-phase in time (black line, errors lines in gray) for 3–5 and 6–8 years old left and right panel, respectively. Shuffle events were calculated to compare probability of occurrences (blue line). Eye contact events were locked to the onset and offset of pedagogical episodes (red dotted lines). Bottom right, alignment of probability of referential signal and pedagogical episodes during the T-phase in time (black line, errors lines in gray) for 6–8 years old. Shuffle events were calculated to compare probability of occurrences (blue line). Pedagogical episodes were locked to referential signals events (red dotted line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

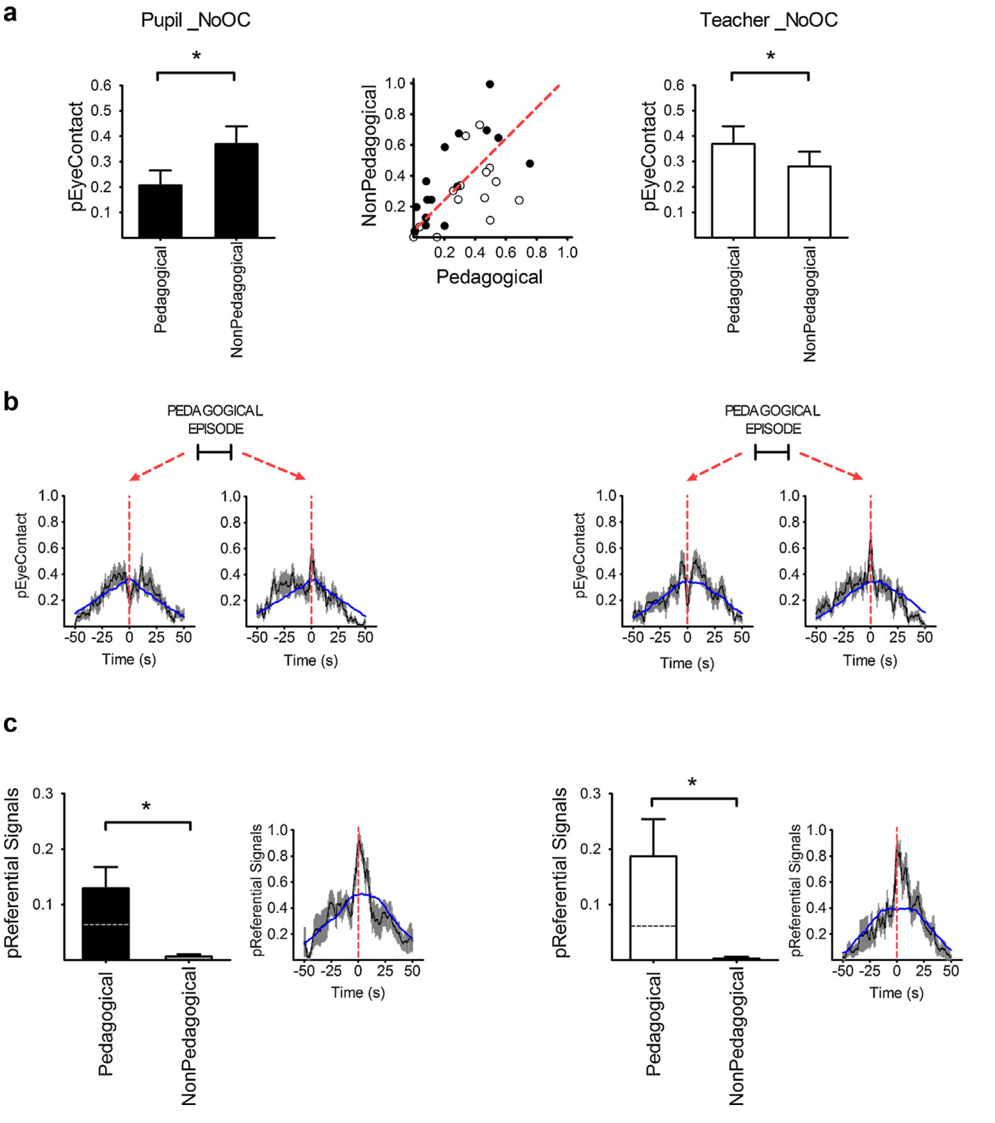

Fig. 2. Changes in the pattern of ostension with interventions which modify the history or context of the pedagogical dialog (a) Probability of eye contacts occurrence in pedagogical and non-pedagogical episodes during the T-phase for 6–8-years old in Studies 2 (Pupil_No_OC, left panel) and 3 (Teacher_No_OC, right panel). Middle panel: scatter plot comparing densities during pedagogical and non-pedagogical events for Pupil_No_OC (black dots) and Teacher_No_OC (open dots) for all participants. (b) Alignment of probability of eye contacts with the adult pupil and pedagogical episodes during the T-phase in time (black line and error in gray lines) for Pupil_No_OC (left panel, pedagogical episodes onset and offset, red dotted arrows and Teacher_No_OC (right panel, pedagogical episodes onset and offset, red dotted arrows). Shuffle events where calculated to compared probability of occurrences (blue line). Eye contact events were locked to the onset and offset of pedagogical episodes (red dotted lines). (c) Probability of referential signals occurrence in pedagogical and non-pedagogical intentions during the T-phase for 6–8-years old in studies 2 (Pupil_No_OC, left panel) and 3 (Teacher_No_OC, right panel) Dotted lines in the both bar graphs represent the referential signals occurrence in pedagogical episodes in the Study 1. Alignment of probability of referential signals and pedagogical episodes during the T-phase in time (black line, error lines in gray) for 6–8-years old. Shuffle events were calculated to compared probability of occurrences (blue line). Pedagogical episodes were locked to referential signals events (red dotted line)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

eye contact is a particularly dense OC (see Appendix Fig. 1a) and it can be manifested in all phases; hence we focused our analysis on this signal, considering that all OC pooled together does not change any of the relevant results reported below.

The density of eye contacts (EC) increased significantly during pedagogical episodes only for the group of young children (see Fig. 1b) (3–5: $t(12) = 2.388$, $p = 0.0478$) and 6–8 years old ($t(11) = 0.425$, $p = 0.679$)). A graded analysis as a function of age for the 31 participant showed a clear and significant progressive decrease of EC with age within pedagogical episodes (see Fig. 1b middle) ($F(1,18) = 7.576$; $p = 0.0093$). Instead, EC did not vary with children's age when averaged across non-pedagogical episodes (see Fig. 1b middle) ($F(1, 18) = 3.981\text{E}{-}05$, $p = 0.995$).

The relation of EC and pedagogical and non-pedagogical episodes found for young children was as predicted in (*H1*); 3–5 years old locked the use of the ostensive channel to moments of pedagogical relevance. However, this relation was not significant when EC for older children was analyzed. These apparent disappearance of the ability to use OC as prosodic markers with age led us to think that, possibly, ostension's dynamics may vary as children got older.

2.2.2. Are OC and gestures two different channels of non-verbal communication that compete during pedagogical episodes?

In order to understand the dynamics of EC during pedagogical episodes and test *H2*; we fine-grained our analysis measuring the dynamics of EC locked to the onset and the offset of those episodes (*onset* and *offset* refers to the beginning and end of the pedagogical episodes). Younger children had dense occurrence of EC locked both to the onset and to the offset of the pedagogical episodes (see Fig. 1c left) (Values for above-chance-level: *onset* $t(11) = 3.078$, $p = 0.0053$ and *offset* $t(11) = 3.852$, $p = 0.0013$). Moreover, the characteristic time in which EC increases significantly from chance is comparable to the average duration of a pedagogical episode (see Fig. 1c and Appendix Fig. 2). Together this implies that younger children increase EC in a sustained manner throughout the entire pedagogical episode.

The temporal pattern was very different for older children. Analysis revealed a biphasic structure with a significant drop of EC (relative to the average in the entire T-phase) at the onset of the pedagogical episode (see Fig. 1c right) followed by a significant increase locked to the end of the pedagogical episode (see Fig. 1c right) (Values for below-chance-level at the *onset* $t(11) = -2.86$; $p = 0.0077$ and values for above-chance-level at the *offset*. $t(11) = 2.762$, $p = 0.0092$).

We found therefore that, as predicted in *H2*, ostensive cues were timely locked to indicate the temporal borders (onset and offset for young children and offset for older ones) of pedagogical episodes. Differences in the dynamics' use of OC between younger and older children led as to support *H3*, showing a change in the distribution of ostension within pedagogical episodes throughout development.

The initial dip in ostension observed in older children may reflect a more sophisticated pattern of gesture orchestration during pedagogy. Specifically, as we hypothesized in *H4*, that, in time, they may parse different channels of non-verbal communication: OC and gestures. We restricted our gesture analysis to Referential signals (RS) (see Materials and Methods). These focus on the content of the pedagogical items (note that during the T-phase, the flowers have been removed from the table so children's gestures refer to mnemonic pointers).

The average density of RS was in fact completely different for younger and older children. Younger children hardly made RS; only one child made a single short (2 second episode) of RS indicating the movement of the monkey to the flower (average density: $M = 0.003$, $SD = 0.012$ for pedagogical and 0 for non-pedagogical episodes and do not appear in a Figure). Instead, almost all older children made RS and the density increased significantly for pedagogical compared to non-pedagogical episodes (RS: $M = 0.066$, $SD = 0.117$ for pedagogical and $M = 0.013$, $SD = 0.013$ for non pedagogical episodes, this data do not appear in a Figure). To quantify this observation we submitted the density of RS to an ANOVA with Episode Type (pedagogical or non-pedagogical) and Age (3–5 or 6–8 years old) as independent factors. The ANOVA revealed a significant effect of Age ($F(1, 48) = 4726$, $p = 0.0347$) and a significant interaction between Age and Episode Type. A post hoc *t*-test revealed that this interaction was accounted by a significant effect of pedagogical Episode type for the 6–8 year old group ($F(1, 24) = 2.714$, $p = 0.0434$) while the difference between pedagogical and non-pedagogical episodes for 3–5 year old children was not significant ($F(1, 24) = 0.998$, $p = 0.3284$).

The dynamics of the density of RS for older children revealed a peak at the onset of pedagogical episodes, coincident with the decrease in EC (see Fig. 1c bottom right) (value for above-chance-level $t(5) = 5.589$, $p = 0.0013$). We note however, that this peak extends broadly indicating that there is not a psychological bottleneck impeding them from emitting simultaneously via ostensive and referential channels. In fact, the density of moments of simultaneous ostensive and referential communication during pedagogical events was significant for older children during pedagogical episodes (Value for above-chance-level $t(5) = 2.527$, $p = 0.0264$).

In summary, the results described above support our hypothesis. We found that younger and older children spontaneously use EC during pedagogical episodes. Younger children, in a simpler way, sustain ostension throughout the episode. Older children do so in a more sophisticated manner. They reveal a finer temporal structure with a sequence of prominent density of RS followed by a dense peak of EC respectively locked to the beginning and the end of the pedagogical episode, alternatively employing different channels of non-verbal communication.

3. Studies 2 and 3

The results show a correlation between pedagogical intention and children ostension and gesturing, nevertheless, it remains to be proven that there is a causal relation between these variables. A way to test this relation would be to change the behavior of the adult teacher and the adult learner. If, as a consequence, the child teacher changes his or her OC and gestures, we could claim that the results found in Study 1 go beyond correlations.

Previous studies showed that children were able to evaluate the quality of information (complete or incomplete) they received from a teacher and also, the quality of the teacher who is transferring that information (Gweon, Pelton, Konpka, & Schulz, 2013). This suggests that children can evaluate teaching episodes with distinctive contexts.

In Studies 2 and 3, we manipulated the source of information (the child's adult teacher) or the recipient of that information (the child's adult learner), respectively and we evaluated changes in the utilization of OC and gestures by the children.

As a consequence, we proposed that if children are naturally pedagogues, i.e. teachers, and they realize that ostensive communication is ineffective – because the recipient will not engage in the adult pupil role, then (*H5*) children would reduce the density of OC and gestures during pedagogical episodes if they sense that it is futile.

Exposing a child to a poor adult teacher may result in different outcomes depending on two alternative hypotheses: (*H6a*) (pedagogical hypothesis) the child should promote non-verbal communication during pedagogical episodes to correct this failure and boost learning. Hence, children will increase ostension as teachers if they learned from a non-ostensive adult teacher; or (*H6b*) (imitation hypothesis) children will decrease ostension as teachers. If the children are purely imitating her prior adult teacher, they will not diagnose the sources of the adult pupil's failure and will not adjust their own teaching accordingly.

3.1. Material and methods

We varied the ostension and gesturing of the adult teacher or student when interacting with two new groups of children. In both studies the adult teacher or adult student minimize OC. The experimenter avoid eye contacts with the child, via lower reactivity, not gesturing, not changing body orientation, no eye-brown raising, no calling the child by name and minimizing pitch changes in the voice.

We conducted Study 2 (Pupil_No_OC) in which the adult pupil minimizes all reception to non-linguistic OC and gestures (*H5*). A total of $n = 16$ children participated in this study (9 boys and 7 girls), $M = 82$ months (6 years and 8 months), ranging from 6 years and 1 month to 7 years and 5 months). The experiment proceeded identically as in Study 1 with the exception that the pupil minimized the use of OC and gestures throughout the entire *Teaching Phase*. From the child's perspective it should turn out to be futile to attempt to establish an ostensive communication.

In Study 3 (Teacher_No_OC), the adult teacher minimized non-linguistic ostensive and gestures communication with the child during the I-phase was carried out to contrast (*H6a*) and (*H6b*). A total of $n = 15$ children participated in this study (9 boys and 6 girls), $M = 86$ months (7 years and 1 months), ranging from 6 years and 2 month to 8 years and 3 months). This Study was identically to Study 1 that the teacher minimized the use of OC throughout the entire *Instruction Phase*. We reasoned that this should give the child the prior that the adult pupil did not learn due to the lack of ostension of the adult teacher. This is the more relevant manipulation of this study for two reasons: (1) The behavior of the experimenter did not change during the T-phase, allowing us to investigate whether a child might change the pattern of ostension and gesturing based on the previous history of pedagogical experience and (2) the pedagogical prediction is opposite to the most natural prediction of what children might do. Based on observation learning and imitation, one would predict that the children who did not receive OC during instruction would be less likely to use them when they switch to a teaching role.

Only 6- to 8-years old children participated of Studies 2 and 3 because we saw in Study 1 that only the older group had a more complex pattern of non-verbal communication in which we could analyze the effects of the interventions. In particular, we were interested to determine if the modification of child's ostension, when she or he teaches an adult pupil who does not return ostensive communication or when the child was exposed to a poor adult teacher herself, was specific to ostensive channels and did not translate to referential signals or if both channels worked together.

The coding system and data analysis were identical to that in Study 1.

3.2. Results

3.2.1. Are children teaching or simple imitating their learning experience?

As hypothesized (*H5*), Study 2 revealed that minimizing the adult pupil's ostension made children significantly reduce the density of EC during pedagogical events compared to the density in non-pedagogical episodes (see Fig. 2a left, $t(14) = 3.225$, $p = 0.0061$). Conversely minimizing the adult teacher's ostension during the I-phase, in Study 3, increased significantly the density of EC during pedagogical events compared to the density in non-pedagogical episodes (see Fig. 2a right, $t(14) = 2.838$, $p = 0.0131$). The effects of both interventions were very reliable and observable in almost every child, as revealed by a scatter plot comparing densities during pedagogical and non-pedagogical events (see Fig. 2a middle). These effects were specific to the relative density of pedagogical and non-pedagogical episodes. We did not observe any significant effect across studies when comparing the density of EC averaged during the entire T-phase (Study 1 $M = 0.226$, $SD = 0.115$; Study 2 (Pupil_No_OC) $M = 0.298$, $SD = 0.118$ and Study 3 (Teacher_No_OC) $M = 0.282$, $SD = 0.116$). Note also that while these two interventions distinctively affect the mean density of ostension between pedagogical and non-pedagogical episodes, the dynamics of EC remains unchanged. In both interventions, as in the main study, we observed for older children a drop of EC at the onset of the episode followed by a peak locked to the end of the episode (see Fig. 2b, (Pupil_No_OC: for *onset* value for below-chance-level $t(14) = -2.311$, $p = 0.0183$ and for *offset* value for above-chance-level; $t(14) = 1.758$, $p = 0.05$) and (Teacher_No_OC values for *onset* below-chance-level; $t(14) = -3.069$, $p = 0.0042$ and for *offset* above-chance-level; $t(14) = 2.682$; $p = 0.0089$); Left and Right, respectively), reinforcing our (*H3*) that the dynamics of ostension develops and is maintained even when the use of OC dramatically change to adjust to new pedagogical contexts.

Referential signals could show different dependencies related to ostension. This imply that during teaching one could encounter different scenarios; (1) If only a non-verbal channel of communication is available then; the modulation or use of RS and OC during a pedagogical episode would be linked, yet (2) if there are several channels that could be exploited independently then; the relation between these signals could be much more complex and rich; because it could vary according to, for example, age, type of discourse, etc. Therefore we hypothesized that either; (*H7a*) the changes in the pattern of RS should be opposite to ostension, if there is an intrinsic competition between referential and ostensive channels, or (*H7b*) RS will increase for both interventions, if in the two manipulations the child understands that he or she ought to increase the gesturing of explanation to facilitate learning.

Analyses of the relative densities during pedagogic and non-pedagogic episodes showed an increase in RS in the pedagogical compared to non-pedagogical episodes for both interventions (see

Fig. 2c: Study 2 (Left) $t(14) = 3.225$, $p = 0.0031$ and Study 3 (Right) $t(14) = 2.838$, $p = 0.0066$). Moreover, there was an increase specific to the pedagogic episodes for both interventions compared to the main study (Study 1 $M = 0.066$, $SD = 0.117$; Study 2 (Pupil_No_OC) $M = 0.129$, $SD = 0.039$ and Study 3 (Teacher_No_OC) $M = 0.1874$, $SD = 0.066$). Together this supports *H7b*, indicating that there is not a fundamental competition between RS and EC (on a way that the increase in EC is accompanied by a decrease in RS). Instead, two manipulations which coincide in creating obstacles in adult pupil OC reception lead children to increase RS signaling. In both interventions, the dynamics of RS shows a pattern similar to that found in Study 1 with a marked peak in the onset of pedagogic episodes coinciding with the drop in ostension. Contrary to Study 1, RS were enhanced even prior to the onset of the pedagogical episode (see Fig. 2c left panel, $t(8) = 3.561$, $p = 0.0016$ and Right panel $t(7) = 3.53$, $p = 0.0017$ (both values for above-chance-level)).

The results found when modifying the non-verbal context of the pedagogical dialog showed that children adjust their own teaching accordingly to their own previous history of learning (Study 3) and the context while they are engaging in a pedagogical episode (Study 2).

4. Discussion

Our work analyzes the production of ostensive cues and gestures during children teaching, bringing together three different literatures. First, the work of Strauss and collaborators showing that children spontaneously engage in teaching (TNCA), revealing an understanding of the intentionality of knowledge transmission (LeBlanc & Bearison, 2004; Strauss & Ziv, 2012; Tomasello & Rakoczy, 2003; Ziv et al., 2008). Second, the theoretical proposal of a natural pedagogy, based on OC, which enables efficient social learning of generic, complete and relevant knowledge (Csibra & Gergely, 2009). Third, the work by Goldin-Meadow and collaborators demonstrating that gestures play an important role in the thought behind communication (Goldin-Meadow, 1999, 2002; Liszkowski, Carpenter, & Tomasello, 2007; Southgate, van Maanen, & Csibra, 2007).

Children's early sensitivity to a channel of ostensive communication to receive generic information (Csibra, 2010; Csibra & Gergely, 2006) and children's spontaneous tendency to teach (Strauss, 2005; Strauss et al., 2002; Tomasello et al., 2005) can be combined to form a suggestion for an expanded theory of pedagogy: Are children also tuned to emit in natural channels of the teacher–learner dyad? Here we showed that young children spontaneously use ostensive cues synchronic with moments of pedagogical intention. We emphasize that the use of ostension by itself is not sufficient to claim pedagogy in the strong definition of natural pedagogy. This requires in addition, the verification of what information (generic, relevant, novel, trustworthy, etc.) is signaled by ostension.

Our work begins to bridge this gap, by showing that eye-contact is more frequent in specific moments relevant to what the children are attempting to teach. Our definition of a pedagogical episode builds on the work of Strauss, Graesser and Roscoe, among others (Csibra & Gergely, 2006; Fuchs et al., 1996; Graesser et al., 1995; Roscoe & Chi, 2007; Strauss et al., 2002; Topping et al., 2003), and considers a moment of discourse as pedagogical if there is explicit communication of information in terms of knowledge content, such as (a) deep explanatory reasoning, (b) anchored learning in specific examples and (c) feedback, error diagnosis, and remediation. This definition resembles but does not completely overlap with the definition of the content of pedagogical information in natural pedagogy. For instance, we consider that referring to a specific example is part of a pedagogical episode even if it does not satisfy the requirement of generality. We mention this explicitly to avoid confusions between the conventional term of "pedagogy", as the science of education, and "pedagogy" as in the theory of *natural pedagogy* which specifically refers to the ostensive transmission of generic knowledge, mostly thought and directed to infants.

We also show that the pattern of ostension and gesturing while teaching changes dramatically during childhood. This is in line with the fact that strategies of teaching evolve, mainly relying on specific examples in children at the age of three years and shifting to more abstract verbal explanations by the age of five (Strauss et al., 2002; Strauss & Ziv, 2012). We showed that younger children (preschoolers) sustain an ostensive channel during the entire pedagogical episode. In contrast, older children show a more refined pattern of gesture orchestration during pedagogy, coordinating in time referential signals and ostension, mostly beginning with explanations and referential gestures and only later establishing eye-contact.

In Study 2 we showed that, as expected, children produce less ostensive communication during pedagogical episodes when the adult pupil is not receptive to them. An interesting and somewhat puzzling observation of this study is that children increased ostension during non-pedagogical episodes. A qualitative analysis of discourse showed that, in this scenario, children spoke more of completely different themes; they talk about their birthday's party, holydays, computer games, etc. A tentative interpretation of this finding is that children are trying to change topics to see whether they can gain the attention of the adult pupil in another subject rather than what they were asked to teach. In so doing, and when making an effort to gain the pupil's attention, they boost ostension. This observation is important for clarifying the specificity of children's ostension to pedagogy. Here we argue that children boost ostension when teaching. However, we do not claim that eye-contact is not used to signal other aspects of communication which are non-generic transmission of knowledge.

Last, by examining how children's history of instruction affects the way they teach we rejected the hypothesis that children teach by simple imitation of their learning experience. Indeed, a child who has been taught by a teacher who avoids ostension does not replicate this behavior but instead ignores it, showing that children can diagnose the sources of the adult pupil's failure and adjust their own teaching accordingly.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cogdev.2015.03.001.

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