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The road to conventional tool use: Developmental changes in children's material engagement with artifacts in nursery school

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Abstract

The development of tool use in early childhood is a topic of continuing interest in developmental psychology. However, the lack of studies in ecological settings results in many unknowns about how children come to use artifacts according to their cultural function. We report a longitudinal study with 17 sociodemographically diverse children (8 female) attending a nursery school in Madrid (Spain) and their two adult female teachers. Using mixed-effects models and Granger causality analysis, we measured changes in the frequency and duration of children's object uses between 7 and 17 months of age and in the directional influences among pairs of behaviors performed by teachers and children. Results show a clear shift in how children use artifacts. As early as 12 months of age, the frequency of conventional uses outweighs that of all other types of object use. In addition, object uses become shorter in duration with age, irrespective of their type. Moreover, certain teachers' nonlinguistic communicative strategies (e.g., demonstrations of canonical use and placing gestures) significantly influence and promote children's conventional tool use. Findings shed light on how children become increasingly proficient in conventional tool use through interactions with artifacts and others in nursery school.

1 | INTRODUCTION

Adaptive tool use in early childhood has always attracted developmental researchers, and its achievement has been considered a crucial milestone for both the phylogenetic history of our species and the ontogenetic development of the child (e.g., Bates et al., 1980; Bühler, 1940/2013; Gesell & Ilg, 1937; Mithen, 1996; Oakley, 1950/1972; Tomasello, 2019; Vygotsky, 1934/2008; Wertsch, 1998). This comes as no surprise, considering that "no other lifeworld, besides the one we call human, can be argued to be constituted, and thus defined on the basis of its changing relationship with the variety of material objects and technologies that it makes and uses" (Ihde & Malafouris, 2019, p. 197). We make tools, but tools also make us: by enveloping our everyday thinking and experience, they mediate and constitute our ways of being and developing in the world (Moro, 2015). In that respect, studying *material engagement* (i.e., how we think *with* and *through* materiality; Malafouris, 2020b) and how it changes throughout the lifespan is paramount to the cognitive sciences.

During the last third of the first year of life, children begin to use artifacts according to their cultural function (Rodríguez et al., 2018). Ontogenetically speaking, the fact that children become skillful tool users implies that they have developed a remarkable degree of behavioral adaptability (Hall, 1963) and the ability to grasp the cultural norms of object use (Costall, 2012; Rodríguez, 2012; Sinha, 2009; Wynberg et al., 2022). Instrumental behavior also brings about a substantial *pragmatic profit* (Alessandroni & Rodríguez, 2019), since it allows children to perceive and explore the world in innovative ways, which in turn leads to the creation of new possibilities for action and new forms of communication with others (Adolph, 2019; Lockman, 2005; Malafouris, 2020a). Despite the significance of tool use, important questions about how children learn to use everyday artifacts in ecologically realistic settings remain unanswered (Rachwani et al., 2020; Riede et al., 2021). One such question concerns the social nature of tool use development. There is broad agreement that tool use develops within socio-material practices in which adults (e.g., parents and teachers) modulate children's possibilities for action through both linguistic and nonlinguistic communicative strategies (e.g., Csibra & Gergely, 2009; Manzi et al., 2020; Nomikou et al., 2016; Okumura et al., 2020; Uzgiris, 1977). However, there is a lack of research describing the everyday interactive dynamics through which children become proficient tool users.

In recent years, several studies have begun to shed light on the issue. For example, Koda et al. (2006) observed the eating behavior of 32 toddlers from 10 to 14 months of age in a nursery school in Japan. They found that as children grew older, the rate at which they ate by themselves using tools increased. In addition, they reported that those who started walking earlier were more active in eating with tools. Similarly, Ishiguro (2016) described how routine interactions at a day-care center in Japan allowed a child to transition from other-assisted to self-organized eating during mealtimes. On a related note, through two case studies at a nursery school, Rodríguez et al. (2017) and Rodríguez and Moreno-Llanos (2020) argued that canonical uses of objects are closely linked to the early development of executive functions during the first year of life. Likewise, Estrada (2019) identified and described three types of educational situations and seven types of mediation strategies that nursery-school teachers use to guide children's participation in activities involving objects, and Belza et al. (2019, 2020) studied how nursery-school teachers introduce conventional tool use to promote greater degrees of autonomy in 2- to 3-year-olds. Meanwhile, Nonaka and Goldfield (2018) and Nonaka and Stoffregen (2020) examined how caregiver-toddler interactions enable the development of the utensil-using skill—both at the home and the nursery school—and Alessandroni (2021) analyzed changes in how children from 5 to 17 months interact in the nursery school, focusing on the development of conventional object use. These and other studies addressing the close intertwinement between materiality and cognitive development (e.g., Alessandroni et al., 2020; Brandone et al., 2020;

Cavalcante et al., 2018; Dimitrova & Moro, 2013; Hallam et al., 2016) highlight the need for further research about the intersubjective contexts where tool use develops and the processes by which objects become meaningful *in* and *through* material engagement.

1.1 | Current study

We explored developmental changes in children's material engagement with objects through longitudinal observations carried out in a nursery school over 10 months. Previous studies in home settings showed that children begin to use artifacts according to their cultural function around their first birthday (see Rodríguez et al., 2018). Accordingly, we were interested in examining the particularities of such a shift in object use in nursery school. More specifically, we asked about the developmental trajectory of conventional object use in the natural setting of the 0–1 classroom of the nursery school during feeding-related activities. To answer this question, we assessed the longitudinal variations in the frequency and duration of the different types of object use that children perform. Given the lack of studies addressing how adults modulate children's opportunities for action in everyday settings, we were also interested in the educational actions performed by teachers to accompany and promote children's tool use. Finally, to shed light on the variations in the dynamics of interactions in nursery school, we quantitatively examined the directional influences among pairs of behaviors performed by teachers and children.

2 | METHOD

2.1 | Participants

Participants for this study included 17 sociodemographically diverse children (8 female) attending two 0–1 classrooms at a public nursery school in Madrid (Spain) and their two adult female teachers. Even when all children were at the same educational level (0–1 classroom), their ages were dissimilar. For this reason, only eight children were present at the beginning of the study. The rest of the children joined later, when they were old enough to stay in school for the whole day. Children's mean age was 8.07 months ($SD = 0.84$ months) at the beginning of the study and 14.31 months ($SD = 1.75$ months) at the end of the study. None of the toddlers used artifacts in a canonical way at the beginning of the observation period. Due to health issues or other reasons, some children were not present at specific sessions. These conditions, typical of studies conducted in real-world settings, posed some challenges for data analysis, which we discuss below. From start to finish, the study allowed us to follow children's instrumental behavior between 7 and 17 months. The present study was conducted according to guidelines laid down in the Declaration of Helsinki. Written informed consent was obtained from children's parents, teachers, and the principal of the nursery school before data collection. All procedures involving human subjects in this study were approved by the Research Ethics Committee at the Universidad Autónoma de Madrid (CEI-88-1666).

2.2 | Procedure

Over 10 months (October 2018–July 2019), a researcher visited the nursery school once a month per classroom and stayed during the hours when the main educational activities took place (9 a.m.–1

p.m.). Teachers informed the researcher that both classrooms could eventually be combined into one large group depending on the activities planned for each day. This happened on five occasions, at the beginning and the end of the school year. As a result, 15 whole school days were filmed. For this study, only data from the two feeding-related activities were considered: the *fruit time* (i.e., a short activity during which teachers provide children with water and fruit, either as purée, bite-sized pieces, or large pieces) and the *main meal* (i.e., lunch). The study was restricted to these two activities because of their routinized nature. This ensured that the different sessions were comparable.

The start of each activity was considered to be when teachers made a verbal announcement about it (e.g., "let's eat some fruit") or when they started arranging the material layout for the activity (e.g., setting up the tables and chairs), whichever came first. The end of each activity was considered to be when teachers moved the last child from the table to another area of the classroom to start a different activity. The researcher filmed activities by placing a video camera attached to a tripod in front of the group, ensuring that the recording angle allowed for the subsequent identification of the children's actions. The researcher remained silent and as still as possible during the filming to avoid disturbing the interactive dynamics. The mean duration of videos was 14.51 min ($SD = 5.52$ min) for the *fruit activity* and 34.8 min ($SD = 5.84$ min) for the *main meal*. During these activities, children had access to the following objects: pacifiers, bibs, feeding bottles, baby cups, spoons, plates, yoghurt cups, and a wooden tray. The researcher did not provide teachers with any instructions on how to act so as to preserve the ecological conditions of interaction.

2.3 | Data coding

Video files were imported into BORIS, an event-logging software for video/audio coding (Friard & Gamba, 2016). The researcher coded behaviors performed by children and teachers using a predefined ethogram with behavioral categories used in previous studies. The categories for children's behaviors were: (1) *object uses*, (2) *gestures*, (3) *attention* to canonical events, and (4) *bodily anticipations*. Teachers' behaviors were coded using the following categories: (1) *demonstrations of object uses*, (2) *gestures*, (3) *body adjustments*, (4) *changes to the classroom layout*, and (5) *language*. A detailed list of the behavioral categories, subcategories, and related examples can be found in Table 1. A second researcher independently coded 40% of the recordings (six out of 15 sessions). Kappa inter-observer reliabilities ranged from 0.74 to 1, indicating a substantial or almost perfect degree of agreement (Landis & Koch, 1977) between coders for all sessions ($M = 0.93$, $SD = 0.04$) and behavioral categories (uses: $M = 0.89$, $SD = 0.07$; gestures: $M = 0.89$, $SD = 0.08$; demonstrations: $M = 0.98$, $SD = 0.02$). Disagreements between the researchers were discussed to refine the categories for future studies. Timed-event data for all sessions were exported as aggregated events to a spreadsheet file. Each row of the file contained information about a specific behavior, the object it was performed with, the session in which it took place, the subject who performed it, its onset, its offset, and its duration.

2.4 | Data analysis

Analysis of the data was performed using the R language and environment for statistical computing (R Core Team, 2020) within R Studio (v. 1.4.1103), and MATLAB (R2020b). Data wrangling and the calculation of descriptive statistics were done in R using functions from the *tidyverse* suite of packages (Wickham et al., 2019). As mentioned earlier, our dataset has missing data points, which is common in human research (Krueger & Tian, 2004). For this reason, we analyzed longitudinal variations in

TABLE 1 Behavioral categories used in the study.

Children	Teachers
Object uses	Demonstrations of object uses
a. *Noncanonical use*: nonspecific behavior with an object that does not follow the cultural norms of object use (e.g., sucking on a spoon handle).	a. *Demonstration of rhythmic-sonorous use*: performing a rhythmic-sonorous use for the child.
b. *Rhythmic-sonorous use*: nonspecific behavior with an object exhibiting a rhythmic and/or sonorous organization (e.g., banging an object). Rhythmic-sonorous uses allow children to develop more controlled, skilled, and efficient forms of percussive action (Kahrs et al., 2012; Kahrs & Lockman, 2014) and are precursors to canonical uses.	b. *Incomplete demonstration of canonical use*: partially performing a canonical use for the child, thus posing a challenge to him/her (e.g., placing a bib at the level of the child's forehead for him/her to finish putting it on).
c. *Proto-canonical use*: ineffective behavior with an object that nevertheless approximates a conventional object use (e.g., drinking from a feeding bottle without lifting it properly).	c. *Demonstration of canonical use*: performing a canonical object use for the child.
d. *Canonical use*: dexterous instrumental behavior that follows the cultural norms of object use (e.g., eating with a spoon).	d. *Demonstration of symbolic use*: performing a symbolic object use for the child.
e. *Symbolic use:* instrumental behavior involving pretending (e.g., "eating" with an empty spoon).	
Gestures	Gestures
a. *Self-directed ostension*: Showing an object to oneself (e.g., to explore it) as a way of cognitive self-regulation.	a. *Showing gesture*
b. *Showing gesture*: Showing an object to others by holding it in a directed manner.	b. *Giving gesture*
c. *Giving gesture*: Offering an object.	c. *Reaching gesture*
d. *Reaching gesture*: Trying to reach an object in an effortful manner.	d. *Placing gesture*
e. *Placing gesture*: Deliberately placing an object in a specific spot.	e. *Touch-pointing gesture*
f. *Touch-pointing gesture*: Touching an object with an outstretched finger.	f. *Request gesture*
g. *Request gesture*: Extending an open hand to request an object.	g. *Pointing gesture*
h. *Pointing gesture*: Directing an outstretched finger toward a distant object.	h. *Symbolic gesture*
i. *Symbolic gesture*: Performing a movement that has an arbitrary cultural meaning, for example, shaking the head to deny.	*Body adjustment:* Adjusting or correcting the child's posture according to the requirements of an educational activity.
Attention to canonical event: Looking at canonical behaviors performed by other children (i.e., uses) or the teacher (i.e., demonstrations).	*Change to the classroom layout:* Rearranging the objects in the classroom so as to create the material conditions for an educational activity.
Bodily anticipation: Bodily movement that anticipates an unfinished instrumental action by the teacher. Example: Moving the torso forward while the teacher offers a spoon full of food.	*Language:* Directing linguistic utterances, songs, or vocalizations to the child.

children's instrumental behavior using a *mixed-effects model* approach. Mixed-effects models are extensions of linear regression models that use fixed and random effects in the same analysis. They are an increasingly used statistical tool for modeling changes over time, providing notable advantages over traditional statistical approaches (e.g., repeated-measures ANOVA). For instance, they can capture the stochastic variability in the data that comes from different sources (e.g., participants and items), handle randomly missing data (i.e., they employ all available data per participant), and include time as a numerical factor rather than as a categorical one (see Singmann & Kellen, 2019; Walker et al., 2019). Importantly, when the assumption that residuals follow a normal distribution is not met, *generalized linear mixed-effects models* (GLMMs) allow specifying a different residual distribution and link function while including random effects.

2.4.1 | Mixed-effects models

We used mixed-effects models to assess longitudinal variations in the frequency and duration of different object uses performed by children. All models were fitted using the *glmmTMB* R package (Brooks et al., 2017). In cases where competing models were considered, we chose the most parsimonious one according to the Akaike Information Criterion (AIC). Model fit was assessed through a simulation-based approach using the diagnostic tools provided by the *DHARMa* package in R (Hartig, 2021). No significant problems were detected for any of the models reported in the results. We also computed marginal and conditional r-squared values using the *performance* R package (Lüdecke et al., 2021). Model visualizations and predictions were generated via the *ggeffects* R package (Lüdecke, 2018), and trend comparisons were made through the *emmeans* R package (Russell, 2021). For all models, the variable *age* (expressed in months) was centered by subtracting its minimum value and included as a discrete numerical factor. Symbolic uses of objects were not included in the analysis, as they were very few and only performed by one child in one session.

For the analysis of frequencies, the response variable was defined as the *rate/min* relative to each type of object use (i.e., number of uses performed by each child during each session divided by the total duration of that session). Given the non-negative, continuous, and positively skewed nature of the response, we fitted a by-subject random intercepts GLMM with Gamma family and log link function. Fixed effects included *type of object use* (i.e., non-canonical, rhythmic-sonorous, proto-canonical and canonical) and the *age* × *type of use* interaction. An alternative model that included *activity* (fruit vs. main meal) as a fixed effect failed to find significant differences and was therefore ruled out. An attempt was made to fit a model with by-subject random intercepts and by-subjects random slopes for *age* plus their correlation, but this model generated convergence problems and was discarded.

For the analysis of durations, the *duration* of each use was defined as the response variable. The distribution of the response variable, also non-negative, continuous, and positively skewed, made us opt for a GLMM with Gamma family and log link function. Eleven different models were compared. The best-fit model, carrying 63% of the cumulative model weight, included the following fixed effects: *type of object use*, *age*, *activity* (fruit vs. main meal), and the *age* × *type of use* and *age* × *activity* interactions. As random effects, by-subject and by-object random intercepts and by-subject and by-object random slopes for *age* were included.

2.4.2 | Granger causality analysis

To analyze the directional influence among pairs of behaviors performed by teachers and children, we used *Granger causality analysis*. This method quantifies the extent to which the values of one time

series predict those of a different time series. It produces two measures: a G-cause value that indicates the magnitude of the directional influence and a significance test result, which is used to determine whether the influence is statistically significant and its valence (i.e., positive or negative). After viewing the videos and considering the descriptive statistics, we decided to run the analysis using four behavioral time series for teachers (*incomplete demonstrations of canonical use*, *demonstrations of canonical use*, *body adjustments* and *placing gestures*) and four behavioral time series for children (*attention*, *canonical uses*, *reaching gestures*, and *self-directed ostensions*). For each subject and session, binary-state time series corresponding to the selected behaviors were exported from BORIS with a sampling rate of 1hz. The analysis was performed in MATLAB using the procedure and scripts provided by Xu et al. (2020). The length of the history window for prediction model fitting was set to 3 (equivalent to 3 s, given our sampling rate). This allowed us to focus on the more immediate drivers of behavior rather than on potential distal determinants, whose influence would have been less evident in the context of the interactions we analyzed. In total, we computed 56 directional links between pairs of behavioral variables, of which the most relevant 13 were selected for reporting in this study (Table 7). We considered a directional link as relevant whenever: (i) G-cause values were statistically significant for at least two sessions, (ii) significant G-cause values were not randomly distributed across sessions but reflecting a longitudinal effect or trend, and (iii) longitudinal effects or trends were related to the rest of the results reported in this manuscript.

3 | RESULTS AND DISCUSSION

3.1 | Children's behaviors

Across all sessions, children performed 11,740 behaviors. The most frequent were *attention to canonical events* ($n = 4014$, 34.19%), *canonical uses* ($n = 2302$, 19.61%), *bodily anticipations* ($n = 1038$, 8. 84%), *proto-canonical uses* ($n = 1003$, 8.54%), *reaching gestures* ($n = 919$, 7.83%), *self-directed ostensions* ($n = 904$, 7.70%), and *non-canonical uses* ($n = 732$, 6.24%). Less frequent behaviors were *rhythmic-sonorous uses* ($n = 441$, 3.76%), *pointing gestures* ($n = 145$, 1.24%), *giving gestures* ($n = 93$, 0.79%), *touch-pointing gestures* ($n = 48$, 0. 41%), *symbolic gestures* ($n = 31$, 0.26%), *placing gestures* ($n = 22$, 0.20%), *request gestures* ($n = 22$, 0.19%), *showing gestures* ($n = 15$, 0.13%), and *symbolic uses* ($n = 9$, 0.08%). Table 2 shows the descriptive statistics for children's behaviors and their Winsorized correlations with age.

Overall, canonical uses were the most frequent, followed by proto-canonical, non-canonical, and rhythmic-sonorous uses. This same ranking applies to the durations of uses and the percentages of time they occupy per session. For canonical uses, we found significant positive correlations between the rate/min and the age of children and between the percentage of time and the age of children. Together, these results suggest that children perform more canonical uses and spend more time per session on them as they get older. We also found a significant (albeit slight) negative correlation between the duration of proto-canonical uses and age, indicating that these uses become shorter in duration over time.

In terms of gestures, the most frequent, longest in duration, and taking up most of the time were self-directed ostensions, followed by reaching gestures. A slight significant negative correlation between the duration of self-directed ostensions and age suggests that as children get older, the duration of these gestures decreases. Robust correlation coefficients also indicate that children attend to canonical events more often and for more extended periods as they age. In turn, they perform less bodily anticipations and spend less session time on this behavior.

TABLE 2 Descriptive statistics for children's behaviors and their correlation with age.

Behavior	Statistic	*Mdn* (IQR)	Correlation with age
Attention	Rate/min	0.68 (0.59)/min	0.45**
	% time	3.09 (2.93)%	0.46**
	Duration	2 (1.75) s	0.04*
Bodily anticipation	Rate/min	0.18 (0.28)/min	−0.45**
	% time	0.29 (0.55)%	−0.45**
	Duration	3 (3) s	n.s.
Object uses			
Noncanonical	Rate/min	0.11 (0.17)/min	n.s.
	% time	0.85 (1.38)%	n.s.
	Duration	3.5 (4.5) s	n.s.
Rhythmic-sonorous	Rate/min	0.07 (0.11)/min	n.s.
	% time	0.53 (0.89)%	n.s.
	Duration	3 (3.25) s	n.s.
Proto-canonical	Rate/min	0.16 (0.26)/min	n.s.
	% time	1.58 (2.18)%	n.s.
	Duration	4.50 (5.25) s	−0.12*
Canonical	Rate/min	0.53 (0.76)/min	0.49**
	% time	4.89 (6.02)%	0.47**
	Duration	4.5 (4) s	n.s.
Gestures			
Reaching	Rate/min	0.11 (0.13)/min	n.s.
	% time	0.60 (0.86)%	n.s.
	Duration	2.25 (2) s	n.s.
Self-directed ostension	Rate/min	0.13 (0.18)/min	n.s.
	% time	0.72 (1.14)%	n.s.
	Duration	2.75 (2.75) s	−0.08*
Pointing	Rate/min	0.04 (0.06)/min	n.s.
	% time	0.14 (0.3)%	n.s.
	Duration	2.25 (2.5) s	n.s.

Note: *$p < 0.05$, **$p < 0.01$. We report the medians and IQRs due to the non-normality of most of the distributions.

Children performed unequal numbers of uses with each object. Of the 4478 total uses, 3258 (72.8%) were with spoons, 502 (11.2%) with baby cups, 297 with feeding bottles (6.63%), and 421 (9.37%) with other objects. On average, the onset of proto-canonical uses occurred at 10 months ($SD = 1.49$ months) and that of canonical uses at 11.3 months of age ($SD = 1.17$ months). Table 3 shows the average onsets of proto-canonical and canonical uses for different objects. There is variability between (i) the average onsets for a given type of use across different objects, (ii) the differences between both average onsets for a given object, and (iii) the percentages of children who materially engaged in a proto-canonical and canonical fashion with different objects. For example, all children performed proto-canonical uses with the spoon at about 10.8 months of age, and most of them (94%) also performed canonical uses, on average, 1 month later.

TABLE 3 Average onsets (*SD*) of proto-canonical and canonical uses for different objects.

Object	Onset of PCU [*M* (*SD*)]	*n* (%) of children who performed PCU	Onset of CU [*M* (*SD*)]	*n* (%) of children who performed CU
Spoon	10.8 (1.46)	17 (100%)	11.8 (0.94)	16 (94%)
Feeding bottle	10.7 (2.12)	11 (65%)	12.2 (1.96)	12 (71%)
Pacifier	9.88 (2.27)	3 (18%)	12.9 (0.96)	4 (24%)
Bib	13 (2.17)	9 (53%)	12.9 (1.65)	8 (47%)
Cup	12.8 (1.88)	13 (76%)	13.4 (1.47)	16 (94%)
Tray	14.9 (1.90)	3 (18%)	15.2 (1.04)	9 (53%)

Abbreviations: CU, canonical use; PCU, proto-canonical use.

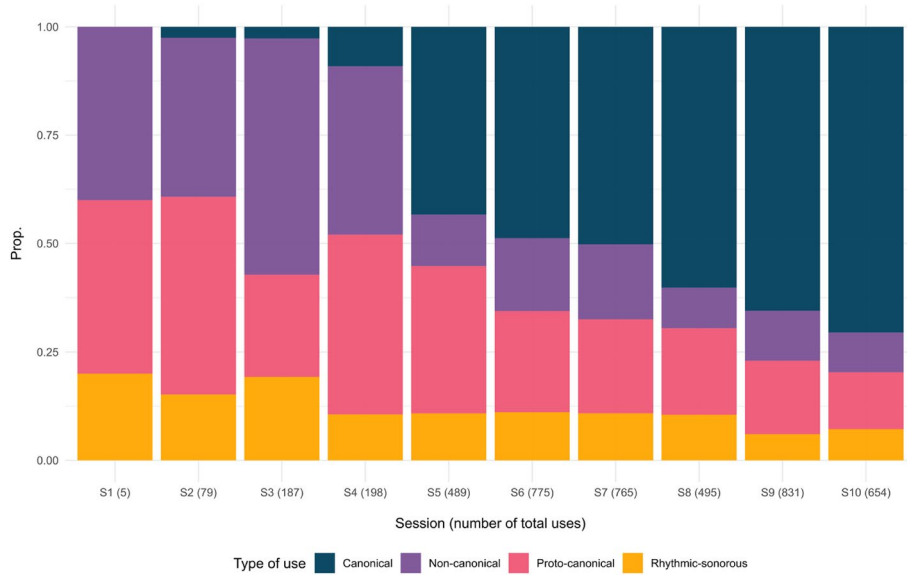

FIGURE 1 Relative frequencies of object uses performed by children in each session.

Meanwhile, only a small portion of children performed proto-canonical (18%) or canonical (24%) uses with the pacifier, and the difference between the average onsets for this object is three times larger than in the case of the spoon. There are varying degrees of dispersion in the distributions of onsets corresponding to different objects. The spoon, for example, is the object whose magnitude of dispersion is smallest for onsets of both types of uses as reflected by the standard deviation values. While a detailed analysis of what happens with each object is beyond the scope of this paper, our results show that there are specific *material engagement profiles* for different objects that are worth exploring in future studies.

Visualizing the relative frequencies of object uses performed by children in each session (Figure 1) brings to light important insights. In the first session, uses were very few ($n = 5$), and none were canonical. During the first four sessions, most of the uses were non-canonical or proto-canonical, although a few canonical uses were recorded. In the fifth session, the number of uses increased sharply ($n = 489$ vs. $n = 198$ in the previous session), and canonical uses reached 43.35% (vs. 9.09% in the previous session). In subsequent sessions, the percentage of canonical uses increased without exception, while the percentages of proto-canonical, rhythmic-sonorous, and non-canonical uses decreased.

Overall, these results suggest that as the school year progresses, children become more proficient tool users and perform an increasing proportion of canonical uses. However, because there were children of different ages in each classroom, it is difficult to disentangle from Figure 1 the precise effect of age on the frequency of each type of use. We next present the results of the mixed model analysis to shed light on the issue.

3.1.1 | Longitudinal variations in frequencies

Details of the mixed model assessing longitudinal variations in frequencies of uses can be found in Table 4. The model's total explanatory power was substantial (conditional $R^2 = 0.40$), and the part related to the fixed effects alone (marginal R^2) was of 0.35. The estimated residual variance was 0.74, and the estimated between-subject variance was 0.06, indicating that the variability of the intercept across children was low (ICC = 0.07).

The model's intercept, corresponding to 7 months of age and canonical uses, was at $\exp(-2.11) \approx 0.12$ uses/min ($p < 0.001$). Statistically nonsignificant effects of proto-canonical uses, rhythmic-sonorous uses, and non-canonical uses showed that, when age is 7 months, the differences between the expected rates/min for these types of uses are mutually indistinguishable from that of canonical uses. Importantly, the effect of *age* was statistically significant and positive ($\beta = 0.25$, $p < 0.001$). For the *type of use* reference level (i.e., canonical uses), the model estimated a multiplicative increase in the rate/min of $\exp(0.25) \approx 1.29$ per month of age. Estimates for the interaction effect of *age* on proto-canonical uses, rhythmic-sonorous uses, and non-canonical uses were statistically significant. Rates/min for proto-canonical and rhythmic-sonorous uses increase slower than that of canonical uses at a multiplicative rate of $\exp(0.25–0.21) \approx 1.04$ and $\exp(0.25–0.17) \approx 1.08$ per month, respectively. In contrast, non-canonical uses decrease at a multiplicative rate of $\exp(0.25–0.31) \approx 0.94$ per month of age. Figure 2 shows the longitudinal changes in the rates/min for all types of uses.

We also performed Tukey-corrected post-hoc pairwise comparisons for the slopes of the *age* trend over the different levels of *type of use*. Statistically significant differences were found between slopes of the *age* trend for canonical uses and non-canonical uses ($p < 0.001$) and between slopes for canonical uses and proto-canonical uses ($p = 0.03$). Differences between canonical and rhythmic-sonorous uses, non-canonical and proto-canonical uses, non-canonical and rhythmic-sonorous uses, and

TABLE 4 Mixed-effects model: Longitudinal variations in frequencies of uses.

Parameter	Estimate	*SE*	95% CI	*z*	*p*
Intercept (reference = CU)	−2.11	0.39	[−2.88, −1.35]	−5.43	**< 0.001**
– PCU	0.29	0.45	[−0.60, 1.18]	0.64	0.519
– RSU	−0.57	0.45	[−1.45, 0.30]	−1.28	0.201
– NCU	0.51	0.43	[−0.34, 1.36]	1.17	0.241
Age × type of use (reference = CU)	0.25	0.06	[0.13, 0.38]	4.01	**< 0.001**
– PCU	−0.21	0.08	[−0.36, −0.06]	−2.72	**0.006**
– RSU	−0.17	0.08	[−0.32, −0.03]	−2.33	**0.020**
– NCU	−0.31	0.07	[−0.46, −0.17]	−4.32	**< 0.001**

Note: Bold indicates statistically significant results with a *p*-value less than 0.05. Coefficients are reported on the log scale. Model syntax: rate ~ age * use + (1 | child). Random effects: σ^2: 0.74; $\tau 00$ (child): 0.06; ICC: 0.07. Marginal R^2: 0.348. Conditional R^2: 0.397.

Abbreviations: CU, canonical use; NCU, noncanonical use; PCU, proto-canonical use; RSU, rhythmic-sonorous use.

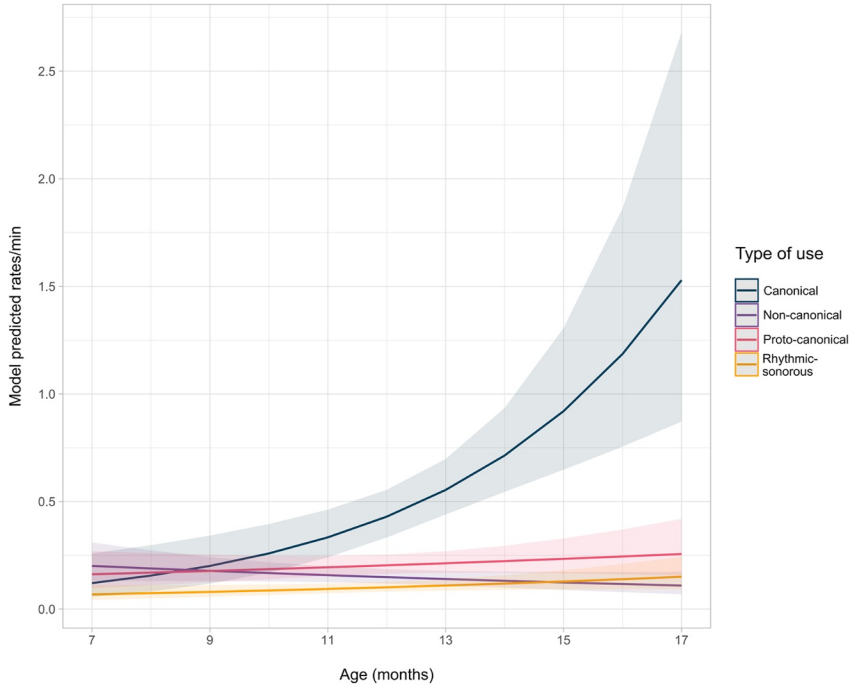

FIGURE 2 Model-predicted changes in object uses rates/min across age.

proto-canonical and rhythmic-sonorous uses were not significant. As a whole, results show that as children grow older, the frequency of canonical uses increases substantially, while that of non-canonical uses declines. Although the frequency of proto-canonical and rhythmic-sonorous uses increases with age, it does so only moderately. When children are 7 months old, the rates/min of the four types of object use are almost indistinguishable. However, from 12 months of age onward, the rate/min of canonical uses is clearly differentiated from that of the other types of object use. This finding is consistent with studies that investigated developmental changes in early object play and exploration and reported a gradual transition from undifferentiated behaviors (e.g., mouthing or simple manipulation) to more specific behaviors that include conventional and symbolic uses of objects (e.g., Belsky & Most, 1981; Pellegrini & Hou, 2011; Rocissano, 1982; Vauclair & Bard, 1983; Zelazo & Kearsley, 1980).

3.1.2 | Longitudinal variations in durations

Table 5 includes the details of the mixed model concerning the durations of object uses. The model's total explanatory power was moderate (conditional $R^2 = 0.22$), and the part related to the fixed effects alone (marginal R^2) was of 0.05. The estimated residual variance was 0.43, the estimated between-subject variance was 0.06, and the estimated between-object variance was 0.02 (ICC = 0.18).

The model's intercept, corresponding to canonical uses of objects, 7 months of age, and the fruit activity was at $\exp(2.12) \approx 8.33$ s ($p < 0.001$). Effects of proto-canonical uses and rhythmic-sonorous uses indicated that, for the reference levels, the expected durations of these types of object use are significantly different from that of canonical uses. The effect of non-canonical uses was statistically non-significant. We found a statistically significant and negative ($\beta = -0.21$, $p < 0.05$) effect of

TABLE 5 Mixed-effects model: longitudinal variations in durations of uses.

Parameter	Estimate	*SE*	95% CI	*z*	*p*
Intercept (reference = CU/fruit activity)	2.12	0.13	[1.86, 2.38]	16.03	**< 0.001**
– PCU	0.16	0.08	[0.01, 0.32]	2.02	**0.043**
– RSU	−0.42	0.10	[−0.60, −0.23]	−4.39	**< 0.001**
– NCU	−0.17	0.09	[−0.34, 0.01]	−1.89	0.059
Activity (main meal)	−0.21	0.09	[−0.38, −0.03]	−2.33	**0.02**
Age × type of use (reference = CU/fruit activity)	−0.09	0.03	[−0.15, 0.03]	−2.33	**0.002**
– PCU	−0.02	0.01	[−0.05, 0.01]	−1.38	0.167
– RSU	0.02	0.02	[−0.02, 0.05]	1.06	0.287
– NCU	0.003	0.02	[−0.03, 0.04]	0.23	0.818
Age × activity (main meal)	0.03	0.02	[−0.00, 0.07]	1.95	0.051

Note: Bold indicates statistically significant results with a *p*-value less than 0.05. Coefficients are reported on the log scale. Model syntax: duration ~ age * use + age * activity + (age | child) + (age | object). Random effects: σ^2: 0.43; τ00 (child): 0.06; τ00 (object): 0.02; ρ01 (child): −0.83; ρ01 (object): −0.41; ICC: 0.18. Marginal R^2: 0.05. Conditional R^2: 0.223.

Abbreviations: CU, canonical use; NCU, noncanonical use; PCU, proto-canonical use; RSU, rhythmic-sonorous use.

activity (main meal), indicating that, for the reference levels, a use happening during the main meal is expected to be shorter. A detailed consideration of this result is beyond the scope of this article. However, it could be of interest to future studies exploring the differences between activities and objects available in the nursery school.

The effect of *age* was statistically significant and negative ($\beta = -0.09$, $p < 0.01$). For the reference levels, the model predicts a decrease in duration at a multiplicative rate of $\exp(-0.09) \approx 0.91$ per month. Differences in slope between proto-canonical uses and canonical uses ($\beta = -0.02$, $p = 0.167$), rhythmic-sonorous uses and canonical uses ($\beta = 0.02$, $p = 0.287$), and non-canonical uses and canonical uses ($\beta = 0.003$, $p = 0.818$) were statistically nonsignificant. Figure 3 shows changes in duration for all types of uses across age. Tukey-corrected post-hoc pairwise comparisons for the slopes of the *age* trend over the different levels of *type of use* and *activity* revealed no statistically significant differences.

All in all, the model predicts that the durations of all types of object use decrease as children grow older. For instance, between 7 and 17 months of age, the predicted duration of canonical uses in the main meal decreases from 6.76 s (95% CI [5.39, 8.47]) to 3.84 s (95% CI [2.60, 5.68]). This finding can be interpreted as evidence of children's development of tool use expertise. In the beginning, conventional tool use is a daunting challenge for children due to the degree of motor coordination and precision involved (e.g., Connolly & Dalgleish, 1989; Lockman & Kahrs, 2017). As children gain experience, the effort and the amount of time required to perform a canonical use lessen.

3.2 | Teachers' behaviors

From beginning to end of the study, teachers performed 11,701 behaviors. The four most recurrent, which accounted for 90% of all recorded behaviors, were *language* ($n = 5214$, 44.6%), *demonstrations of canonical use* ($n = 3469$, 29.6%), *changes to the classroom layout* ($n = 1350$, 11.5%), and *placing gestures* ($n = 511$, 4.37%). Other behaviors that accounted for at least 1% of total behaviors included *body adjustments* ($n = 494$, 4.22%) and *incomplete demonstrations of canonical use* ($n = 380$, 3.25%). *Symbolic gestures*, *giving gestures*, *showing gestures*, *pointing gestures*, *request*

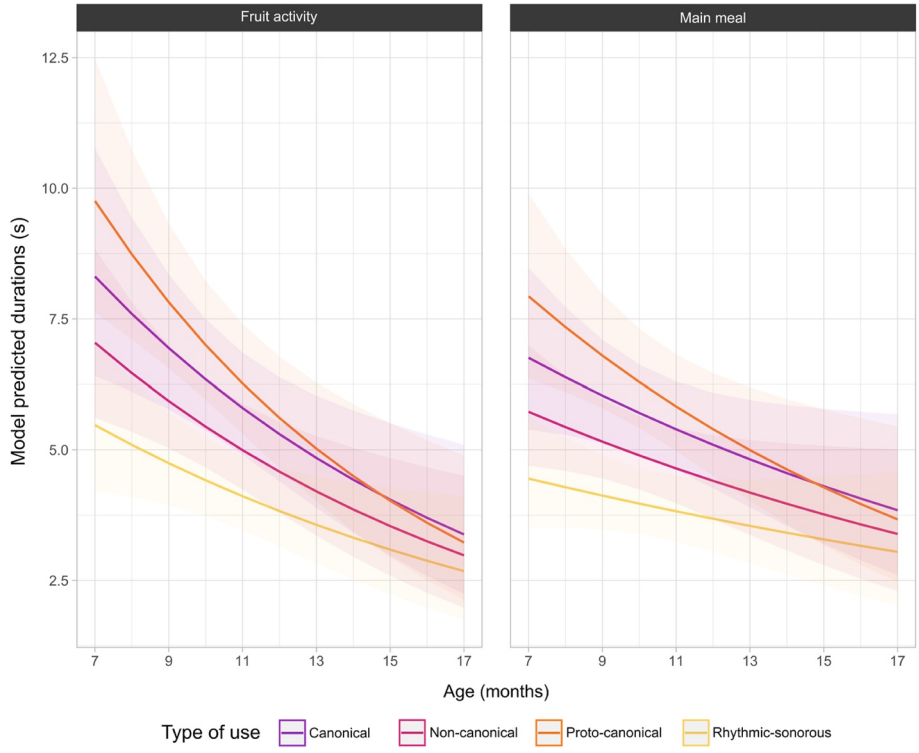

FIGURE 3 Model-predicted changes in object uses durations across age.

gestures, *touch-pointing gestures*, and *demonstrations of symbolic uses* were unusual, representing less than 1% of total behaviors each. Table 6 shows the descriptive statistics for the most relevant behaviors of teachers and their Winsorized correlations with the session number.

Frequency-wise, a moderate positive correlation between the rate/min for placing gestures and the session number suggests that, as time goes by, teachers perform more of these gestures. In line with previous studies (e.g., Estrada, 2019), we interpret the increase in placing gestures as an indicator of teachers' willingness to promote children's agency. Placing an object within children's reach modifies the landscape of affordances (Rietveld & Kiverstein, 2014) to which they have access and can promote culturally privileged forms of action (e.g., canonical uses).

Median time percentages reveal that teachers devoted similar amounts of time to language (17.2%) and canonical demonstrations (17.8%), these being the behaviors that took up the most time. This suggests that further analysis of the functions and effects of language throughout the sessions could be informative. There is a marked difference between the median time percentages for demonstrations of canonical use and incomplete demonstrations of canonical use, despite the similarity in their median durations. Incomplete demonstrations occupy a smaller portion of the sessions, and as suggested by the moderate and negative correlation, this percentage becomes progressively smaller as the sessions go by. This is consistent with a previous study (Alessandroni, 2021), which described how challenging incomplete demonstrations can be for children in cognitive terms. As invitations to complete an unfinished canonical use, incomplete demonstrations are educationally practical only when children can understand what they are being invited to and have the motor capabilities to respond appropriately. At the beginning of the school year, when the manual dexterity that conventional object use requires is not sufficiently developed, it is expected that not much time will be devoted to incomplete

TABLE 6 Descriptive statistics for teachers' behaviors and their correlation with session number.

Behavior	Statistic	*Mdn* (IQR)	Correlation with session number
Language	Rate/min	4.07 (5.24)/min	n.s.
	% time	17.2 (24.2)%	n.s.
	Duration	1.75 (2) s	−0.12**
Demonstrations of canonical use	Rate/min	3.44 (2.86)/min	n.s.
	% time	17.8 (18.4)%	n.s.
	Duration	2.75 (1.75) s	−0.23**
Incomplete demonstrations of canonical use	Rate/min	0.41 (0.39)/min	n.s.
	% time	1.89 (2.74)%	−0.50*
	Duration	2.5 (2.5) s	n.s.
Changes to the classroom layout	Rate/min	1.37 (1.23)/min	n.s.
	% time	5.62 (4.65)%	n.s.
	Duration	1.50 (1.75) s	−0.16**
Placing gestures	Rate/min	0.49 (0.43)/min	0.63**
	% time	1.18 (0.90)%	n.s.
	Duration	1.50 (1) s	n.s.
Body adjustments	Rate/min	0.48 (0.39)/min	n.s.
	% time	2.52 (2.09)%	n.s.
	Duration	1.75 (2) s	−0.24**

Note: *$p < 0.05$, **$p < 0.01$. We report the medians and IQRs due to the non-normality of most of the distributions.

demonstrations. Similarly, once children have mastered conventional tool use, the challenge posed by incomplete demonstrations becomes less meaningful, as they can already engage with artifacts conventionally and autonomously. Statistically significant but negligible negative correlations between the session number and the duration of language, demonstrations of canonical use, changes in the classroom layout and body adjustments indicate that, over time, the duration of these behaviors becomes slightly shorter.

Figure 4 shows the relative frequencies of teachers' most common nonlinguistic communicative strategies and their unfolding over time. Demonstrations of canonical use predominate in all sessions. Although their relative frequency tends to decrease over time, it is consistently above 40% of the total number of behaviors. This suggests that teachers make a ubiquitous and deliberate effort to support children in becoming familiar with the canonical use of artifacts, which is in line with previous studies focusing on how adults scaffold children's learning through shared engagement with objects (e.g., Bornstein et al., 2020; Bornstein & Tamis-LeMonda, 1989; Luo & Tamis-LeMonda, 2016; Nonaka & Stoffregen, 2020; Rossmanith et al., 2014; Schatz et al., 2022; Suarez-Rivera et al., 2022; Zukow, 1986).

Another trend is the relative increase in placing gestures, whose educational and cognitive implications were already mentioned. In the first two sessions, placing gestures represent less than 5% of the nonlinguistic communicative strategies. The percentage rises to 23.5% in the last session.

As for incomplete demonstrations, there is a slight tendency for their relative frequency to decrease between the first and the last sessions, congruent with the above interpretation of their challenging nature for children. Finally, while body adjustments remain relatively stable over time (between 6% and 11% of behaviors), changes to the classroom layout are relatively more frequent in the intermediate

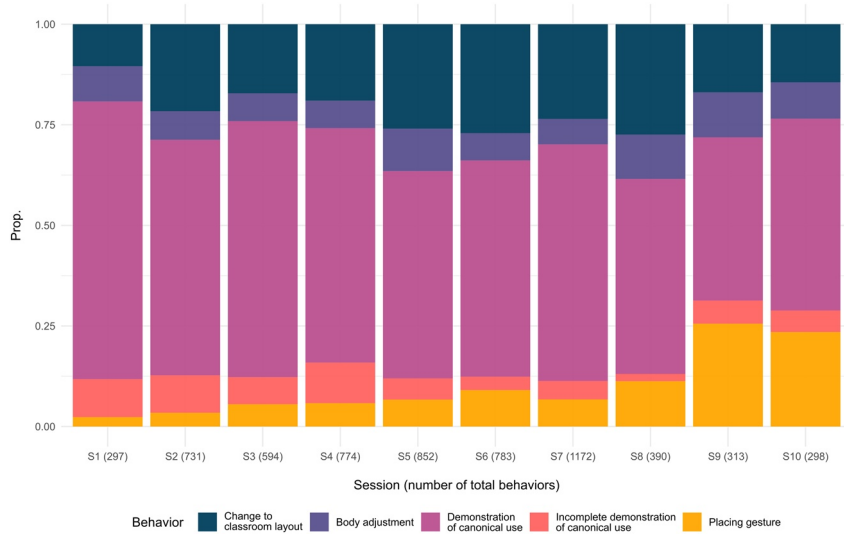

FIGURE 4 Relative frequencies of nonlinguistic communicative strategies employed by teachers in each session.

sessions. Several factors could account for this result. In our study, there were more children in the intermediate sessions than in the first (i.e., more children had already joined each group) and last sessions (i.e., some children stopped attending just before the holiday period). The presence of more children necessitates the organization of more artifacts and other material structures. There were also changes in the type of food provided to children. Initially, teachers only offered water, fruit/vegetable purée, bread, and rarely yoghurt. From the third session onward, teachers offered yoghurt to more and more children, and from the fourth session onward, they progressively introduced bite-sized food (e.g., pasta, pieces of chicken or chickpeas). Besides, teachers gradually transferred control of the feeding situation to the children. Changing the type of food provided and transferring control of the feeding situation to the children require using more artifacts (e.g., plates and spoons), which translates into a greater number of necessary adjustments to the material environment.

3.3 | Directional influences among pairs of behaviors performed by teachers and children

We used Granger causality analysis to assess the directional influences among pairs of behaviors performed by children and teachers (see Table 7). The directional link between *demonstrations of canonical use* and *attention to canonical events* is perhaps the most salient finding. The results show that demonstrations of canonical use particularly attract children from the beginning of the school year, ubiquitously eliciting their attention. This finding resonates with recent research (Deák et al., 2014; Yu & Smith, 2013, 2017) showing that during caregiver-child interactions with objects, infants spend a good deal of time attending to the caregiver's hands and the objects they are holding rather than the caregiver's face. Additionally, there is a significant and positive directional influence between *demonstrations of canonical use* and children's *canonical uses* in sessions 6 (one classroom) and 7 (both classrooms). While demonstrations of canonical use do not increase the likelihood of occurrence of canonical uses at the beginning, they do shortly after the middle of the school year, possibly thanks to the history of demonstrations that teachers direct to children during the first sessions (Figure 4).

TABLE 7 Granger causality analysis results.

	G-cause value (per session)														
Directional link	**S1**	**S2a**	**S2b**	**S3**	**S4a**	**S4b**	**S5b**	**S5b**	**S6a**	**S6b**	**S7a**	**S7b**	**S8**	**S9**	**S10**
Between teachers' behaviors and children's behaviors															
DCU → Att	**29.95**	**11.82**	**13.68**	**143.69**	**31.18**	**32.43**	**93.10**	**88.46**	**160.54**	**59.03**	**110.84**	**76.01**	**56.61**	**38.47**	**34.36**
DCU → CU	0.00	0.00	−0.00	0.00	−1.91	−0.44	0.03	−2.45	0.41	**3.13**	**14.60**	**3.44**	2.11	0.15	0.31
PG → CU	0.00	0.00	0.00	0.00	0.69	0.34	0.09	1.65	−2.11	0.11	**6.28**	1.59	**8.51**	2.33	**−3.81**
PG → RG	1.08	0.02	−0.17	1.86	0.40	−0.00	−0.77	−0.05	−0.00	0.01	**3.34**	−0.20	−0.02	**3.24**	**12.93**
Between teachers' behaviors															
DCU → IDCU	**−4.18**	**−9.61**	**−19.03**	**−18.55**	**−37.69**	1.00	**−8.58**	**−9.00**	**−11.19**	−0.04	**−17.04**	**−8.11**	**121.17**	−0.39	−2.56
DCU → PG	−2.83	−1.34	**−9.94**	**−16.78**	−0.97	−1.64	−1.36	0.89	**−17.26**	**−32.02**	**−3.32**	**−15.74**	**2.82**	−0.25	0.13
PG → DCU	**−45.61**	−0.66	**−12.12**	**−10.50**	**−16.45**	**−6.45**	**−4.96**	**−14.94**	**−77.43**	−0.72	**−5.18**	**−16.72**	**8.93**	**7.41**	0.04
BA → DCU	0.03	−0.67	**−6.90**	**−5.53**	**−13.39**	0.67	−1.54	−1.16	**−71.88**	**−4.59**	**−7.80**	**−30.50**	−0.44	**22.15**	−1.46
Between children's behaviors															
CU → RG	0.00	0.00	0.00	0.00	−0.04	−1.17	−0.11	−0.89	−0.03	**−5.25**	**−3.90**	**−8.39**	**−4.29**	−0.52	−0.38
CU → Att	0.00	0.00	0.00	0.00	0.97	−0.00	−0.16	2.14	−0.22	2.39	**3.72**	0.28	0.96	**5.37**	0.09
RG → SDO	0.00	−0.07	−0.01	**15.73**	−0.06	−1.37	−0.20	−0.16	**15.30**	**4.17**	−0.08	**18.55**	**6.28**	1.71	0.91
RG → CU	0.00	0.00	0.00	0.00	−0.08	−0.00	0.10	−0.23	**−3.53**	−1.66	−2.04	0.08	0.16	**3.08**	−0.38
SDO → CU	0.00	0.00	0.00	0.00	−0.00	−0.09	2.01	**12.03**	**11.54**	0.82	−0.16	1.46	**2.64**	**6.83**	−0.15

Note: Bold indicates statistically significant results. When the letters "a" and "b" do not accompany the session number, this indicates that the two classrooms were combined (see the Method section).

Abbreviations: Att, attention to canonical event (children); BA, body adjustment (teachers); CU, canonical use (children); DCU, demonstration of canonical use (teachers); IDCU, incomplete demonstration of canonical use (teachers); PG, placing gesture (teachers); RG, reaching gesture (children); SDO, self-directed ostension (children).

Relatedly, children's *canonical uses* significantly decrease the likelihood of occurrence of *reaching gestures* in sessions 6–8. This seems to indicate that, as from the sixth session, once children have initiated a canonical use, they are not attracted by and do not try to reach other objects. We interpret this result as indicating a more profound material engagement, not easily disturbed by the close presence of other objects. Moreover, we found a positive and statistically significant link between *canonical uses* and *attention to canonical events* for sessions 7 (one classroom) and 9. In the first sessions, initiating a canonical use does not increase the likelihood of occurrence of attention to canonical events (i.e., demonstrations of canonical use by teachers or canonical uses by other children), but it does toward the end of the school year. This seems to suggest that, over time, children not only become proficient in conventional tool use but also tend to monitor the canonical actions of others after having initiated a canonical action themselves.

On a different note, we found negative influences of *demonstrations of canonical use* on *incomplete demonstrations of canonical use* (significant in sessions 1–7) and on *placing gestures* (significant in sessions 2–3 and 6–7). This effect is reversed for both links in session 8 and is nonsignificant in sessions 9–10. This might be due to teachers not delegating feeding-related actions to children until they can handle them. Thus, in early sessions, when children's canonical or proto-canonical uses are not prevalent, inviting them to complete a canonical use or placing an object within their reach after a demonstration of canonical use does not seem to be relevant for teachers. There is also a negative and statistically significant directional effect of *placing gestures* on *demonstrations of canonical use* in sessions 1–7. Complementary to the previous result, this suggests that when teachers place an object in a child's field of action, they do not rush to regain control of the situation by performing demonstrations of canonical use. This can be seen as a strategy to foster children's autonomy, which is crucial during the early educational stages.

Teachers' *placing gestures* have a statistically significant and positive effect on *canonical uses* in sessions 7 (one classroom) and 8 (but notice the negative result for session 10) and on *reaching gestures* in sessions 7 (one classroom), 9, and 10. This indicates that *placing gestures* promote children's canonical uses and reaching gestures after the middle of the school year. Noteworthy, in the first sessions, *reaching* for an object does not increase the likelihood of occurrence of a *canonical use* (on the contrary, it may even decrease it; see classroom *a* in session 6), but it does increase it in session 9. *Reaching gestures* also exhibit statistically significant positive links with *self-directed ostensions* in sessions 3 and 6–8. This suggests that children reach for an object to explore it more closely as early as session 3, although more systematically in sessions 6–8. Previous studies argued that showing an object to oneself is a self-regulation strategy that facilitates action planning in children (e.g., Basilio & Rodríguez, 2017). Our results support this finding: in sessions 5 (one classroom), 6 (one classroom), 8, and 9, *self-directed ostensions* exhibited a causal influence on the performance of *canonical uses*.

Our analysis only considered pairs of behaviors. Nevertheless, the results clearly point to potential directional influences in longer behavioral sequences (e.g., teachers' placing gestures > children's reaching gestures > children's canonical uses; children's reaching gestures > children's self-directed ostensions > children's canonical uses). Accordingly, it would be interesting for future studies to consider chains of more than two behaviors.

4 | CONCLUSIONS

Our study aimed to provide empirical evidence on the development of tool use in early childhood in the nursery school setting. Using mixed-effects models and Granger causality analysis, we found longitudinal variations in the frequency and duration of children's instrumental behaviors and changes

in the directional influences among pairs of behaviors performed by teachers and children during feeding-related activities. The results show a clear shift in how children use objects. As they grow, children perform more canonical uses and fewer non-canonical uses. Model predictions indicate that proto-canonical and rhythmic-sonorous uses increase in frequency with age but at a much lower multiplicative rate than canonical uses. Consequently, the developmental trajectory of canonical uses progressively distances itself from that of other types of use, with this effect becoming particularly noticeable from 12 months of age onward. Interestingly, all object uses become shorter in duration with age. Overall, our results suggest that children between 7 and 17 months of age become increasingly proficient in conventional tool use, thus performing more culturally specific uses for more time per session and spending less time per use.

The road to conventional tool use is paved with myriad interactive exchanges with artifacts and others. On one hand, changes in children's material engagement involve transitioning to new forms of interaction. For example, as children perform more canonical uses, they anticipate teachers' demonstrations of canonical use less and attend more to canonical events. On the other hand, teachers actively seek to develop children's conventional tool use by employing nonlinguistic communicative strategies. Demonstrations of canonical use are particularly prominent in relative frequency, significantly elicit children's attention in all sessions, and promote children's performance of canonical uses in sessions 6 and 7. Changes to the classroom layout, placing gestures, body adjustments, and incomplete demonstrations of canonical use are also recurrent. As the school year progresses, the scaffolding provided by teachers becomes briefer (e.g., demonstrations of canonical use, changes to the classroom layout, and body adjustments). At the same time, we found evidence of teachers transferring control of the feeding activities to children. For example, placing gestures, whose relative frequency increases over the school year, decreases the likelihood of occurrence of demonstrations of canonical use. This implies that teachers have a strong interest in children developing new forms of action that allow them to become more autonomous.

Although congruent with other studies, results should be interpreted considering the limitations of observational research in ecological settings. The nursery school is a dynamic and hardly predictable context. In our study, this sometimes entailed the absence of some children and the combination of the two 0–1 classrooms. These two aspects can be considered drawbacks of the data collection situation and could be addressed in future studies by ensuring that recording visits only occur when there is an optimum number of participants. Also, increasing the frequency of data collection and the number of children participating in the study and extending the age range considered would improve the robustness of the data analyses. At the same time, future studies could focus on other activities that, unlike those related to food, do not place extensive pressure on the canonical use of a particular object (e.g., spoon). More studies are needed to unravel longitudinal variations in the dynamics of interactions in nursery school and their relationship to the development of tool use.

Finally, our findings have implications for studying the early development of conceptual thinking. Canonical uses are culturally privileged ways of engaging with material kinds (Brinck & Reddy, 2020). As noted in previous studies, once children learn the canonical use of an object, they can generalize it to other objects in the same category (e.g., Booth et al., 2010; Greco et al., 1990; Oakes, 2008; Rodríguez, 2012; Wertsch, 1998), thereby making sense of materiality according to a functional criterion. This highlights the importance of seriously considering the cultural function of artifacts as the basis of conceptual thinking (Nelson, 1973), a task still pending in the field of developmental psychology (Alessandroni & Rodríguez, 2019). Canonical uses of artifacts, due to their normative and recurrent nature, allow children to flexibly tailor their behaviors to changes in local conditions (Adolph, 2019) and align their behavior with socially promoted general forms of action (Kärtner, 2015). In this sense, material engagement can be seen as a medium (Aston, 2020) to

appropriate, sustain, and enact object concepts in early childhood (Alessandroni, 2021). Hopefully, our study will contribute to a better understanding of the constitutive nature of material engagement for cognition and its variations throughout early childhood development.

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CONFLICT OF INTEREST

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REFERENCES

Adolph, K. E. (2019). An ecological approach to learning in (not and) development. *Human Development*, *63*(3–4), 180–201. https://doi.org/10.1159/000503823

Alessandroni, N. (2021). Object concepts and their functional core: Material engagement and canonical uses of objects in early childhood education. *Human Arenas*, *4*(2), 172–195. https://doi.org/10.1007/s42087-020-00119-5

Alessandroni, N., Moreno-Núñez, A., Rodríguez, C., & Del Olmo, M. J. (2020). Musical dynamics in early triadic interactions. A case study. *Psychological Research*, *84*(6), 1555–1571. https://doi.org/10.1007/s00426-019-01168-4

Alessandroni, N., & Rodríguez, C. (2019). On perception as the basis for object concepts: A critical analysis. *Pragmatics & Cognition*, *26*(2/3), 321–356. https://doi.org/10.1075/pc.19027.ale

Aston, A. (2020). How the Cycladic islanders found their marbles: Material engagement, social cognition and the emergence of Keros. *Cambridge Archaeological Journal*, *30*(4), 587–610. https://doi.org/10.1017/S095977432000013X

Basilio, M., & Rodríguez, C. (2017). How toddlers think with their hands: Social and private gestures as evidence of cognitive self-regulation in guided play with objects. *Early Child Development and Care*, *187*(12), 1971–1986. https://doi.org/10.1080/03004430.2016.1202944

Bates, E., Carlson-Luden, V., & Bretherton, I. (1980). Perceptual aspects of tool using in infancy. *Infant Behavior and Development*, *3*, 127–140. https://doi.org/10.1016/S0163-6383(80)80017-8

Belsky, J., & Most, R. K. (1981). From exploration to play: A cross-sectional study of infant free play behavior. *Developmental Psychology*, *17*(5), 630–639. https://doi.org/10.1037/0012-1649.17.5.630

Belza, H., Herrán, E., & Anguera, M. T. (2019). Early childhood education and cultural learning: Systematic observation of the behaviour of a caregiver at the Emmi Pikler nursery school during breakfast. *Infancia y Aprendizaje*, *42*(1), 128–178. https://doi.org/10.1080/02103702.2018.1553268

Belza, H., Herrán, E., & Anguera, M. T. (2020). Early childhood, breakfast, and related tools: Analysis of adults' function as mediators. *European Journal of Psychology of Education*, *35*(3), 495–527. https://doi.org/10.1007/s10212-019-00438-4

Booth, A. E., Schuler, K., & Zajicek, R. (2010). Specifying the role of function in infant categorization. *Infant Behavior and Development*, *33*(4), 672–684. https://doi.org/10.1016/j.infbeh.2010.09.003

Bornstein, M. H., Putnick, D. L., Hahn, C., Tamis-LeMonda, C. S., & Esposito, G. (2020). Stabilities of infant behaviors and maternal responses to them. *Infancy*, *25*(3), 226–245. https://doi.org/10.1111/infa.12326

Bornstein, M. H., & Tamis-LeMonda, C. S. (1989). Maternal responsiveness and cognitive development in children. *New Directions for Child and Adolescent Development*, *1989*(43), 49–61. https://doi.org/10.1002/cd.23219894306

Brandone, A. C., Stout, W., & Moty, K. (2020). Triadic interactions support infants' emerging understanding of intentional actions. *Developmental Science*, *23*(2). https://doi.org/10.1111/desc.12880

Brinck, I., & Reddy, V. (2020). Dialogue in the making: Emotional engagement with materials. *Phenomenology and the Cognitive Sciences*, *19*(1), 23–45. https://doi.org/10.1007/s11097-019-09629-2

Brooks, M. E., Kristensen, K., Van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., & Bolker, B. M. (2017). GlmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R Journal*, *9*(2), 378–400. https://doi.org/10.3929/ETHZ-B-000240890

Bühler, C. (1940/2013). *The child and his family*. Routledge.

Cavalcante, S., Rodríguez, C., & Martí, E. (2018). Early understanding of cardinal number value: Semiotic, social, and pragmatic dimensions in a case study with a child from 2 to 3 years old. *Integrative Psychological and Behavioral Science*, *53*, 397–417. https://doi.org/10.1007/s12124-018-9464-4

Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill in infancy. *Developmental Psychology*, *25*(6), 894–912. https://doi.org/10.1037/0012-1649.25.6.894

Costall, A. (2012). Canonical affordances in context. *Avant*, *3*(2), 85–93.

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, *13*(4), 148–153. https://doi.org/10.1016/j.tics.2009.01.005

Deák, G. O., Krasno, A. M., Triesch, J., Lewis, J., & Sepeta, L. (2014). Watch the hands: Infants can learn to follow gaze by seeing adults manipulate objects. *Developmental Science*, *17*(2), 270–281. https://doi.org/10.1111/desc.12122

Dimitrova, N., & Moro, C. (2013). Common ground on object use associates with caregivers' gesturese. *Infant Behavior and Development*, *36*(4), 618–626. https://doi.org/10.1016/j.infbeh.2013.06.006

Estrada, L. (2019). *Materialidad y prácticas educativas en la Escuela Infantil con niños entre 1–2 años: Una aproximación cultural, semiótica y pragmática*. Ph.D. Dissertation, Universidad Autónoma de Madrid. https://repositorio.uam.es/handle/10486/688559

Friard, O., & Gamba, M. (2016). BORIS: A free, versatile open-source event-logging software for video/audio coding and live observations. *Methods in Ecology and Evolution*, *7*(11), 1325–1330. https://doi.org/10.1111/2041-210X.12584

Gesell, A., & Ilg, F. L. (1937). *Feeding behavior of infants*. Lippincott.

Greco, C., Hayne, H., & Rovee-Collier, C. (1990). Roles of function, reminding, and variability in categorization by 3-month-old infants. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(4), 617–633. https://doi.org/10.1037/0278-7393.16.4.617

Hall, K. R. L. (1963). Tool-using performances as indicators of behavioral adaptability. *Current Anthropology*, *4*(5), 479–494. https://doi.org/10.1086/200419

Hallam, R. A., Fouts, H. N., Bargreen, K. N., & Perkins, K. (2016). Teacher–child interactions during mealtimes: Observations of toddlers in high subsidy child care settings. *Early Childhood Education Journal*, *44*(1), 51–59. https://doi.org/10.1007/s10643-014-0678-x

Hartig, F. (2021). DHARMa: Residual diagnostics for hierarchical (multi-level/mixed) regression models (0.4.1) [R package] https://cran.r-project.org/web/packages/DHARMa/DHARMa.pdf

Ihde, D., & Malafouris, L. (2019). Homo faber revisited: Postphenomenology and Material Engagement Theory. *Philosophy & Technology*, *32*(2), 195–214. https://doi.org/10.1007/s13347-018-0321-7

Ishiguro, H. (2016). How a young child learns how to take part in mealtimes in a Japanese day-care center: A longitudinal case study. *European Journal of Psychology of Education*, *31*(1), 13–27. https://doi.org/10.1007/s10212-014-0222-9

Kahrs, B. A., Jung, W. P., & Lockman, J. J. (2012). What is the role of infant banging in the development of tool use? *Experimental Brain Research*, *218*(2), 315–320. https://doi.org/10.1007/s00221-012-3062-3

Kahrs, B. A., & Lockman, J. J. (2014). Building tool use from object manipulation: A perception–action perspective. *Ecological Psychology*, *26*(1–2), 88–97. https://doi.org/10.1080/10407413.2014.874908

Kärtner, J. (2015). The autonomous developmental pathway: The primacy of subjective mental states for human behavior and experience. *Child Development*, *86*(4), 1298–1309. https://doi.org/10.1111/cdev.12377

Koda, N., Tachibana, Y., Hirose, T., Yasuda, J., Hinobayashi, T., & Minami, T. (2006). Development of eating behavior by japanese toddlers in a nursery school: Relation to independent walking. *Perceptual and Motor Skills*, *103*(1), 145–150. https://doi.org/10.2466/pms.103.1.145-150

Krueger, C., & Tian, L. (2004). A comparison of the general linear mixed model and repeated measures ANOVA using a dataset with multiple missing data points. *Biological Research for Nursing*, *6*(2), 151–157. https://doi.org/10.1177/1099800404267682

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159. https://doi.org/10.2307/2529310

Lockman, J. (2005). Tool use from a perception–action perspective: Developmental and evolutionary considerations. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 319–330). McDonald Institute Monographs.

Lockman, J. J., & Kahrs, B. A. (2017). New insights into the development of human tool use. *Current Directions in Psychological Science*, *26*(4), 330–334. https://doi.org/10.1177/0963721417692035

Lüdecke, D. (2018). ggeffects: Tidy data frames of marginal effects from regression models. *Journal of Open Source Software*, *3*(26), 772. https://doi.org/10.21105/joss.00772

Lüdecke, D., Ben-Shachar, M. S., Patil, I., Waggoner, P., & Makowski, D. (2021). Assessment, testing and comparison of statistical models using R. *Journal of Open Source Software*, *6*(59), 3112. https://doi.org/10.31234/osf.io/vtq8f

Luo, R., & Tamis-LeMonda, C. S. (2016). Mothers' verbal and nonverbal strategies in relation to infants' object-directed actions in real time and across the first three years in ethnically diverse families. *Infancy*, *21*(1), 65–89. https://doi.org/10.1111/infa.12099

Malafouris, L. (2020a). How does thinking relate to tool making? *Adaptive Behavior*, *29*(2), 107–121. https://doi.org/10.1177/1059712320950539

Malafouris, L. (2020b). Thinking as "thinging": Psychology with things. *Current Directions in Psychological Science*, *29*(1), 3–8. https://doi.org/10.1177/0963721419873349

Manzi, F., Savarese, G., Mollo, M., & Iannaccone, A. (2020). Objects as communicative mediators in children with Autism Spectrum Disorder. *Frontiers in Psychology*, *11*, 1269. https://doi.org/10.3389/fpsyg.2020.01269

Mithen, S. (1996). *The prehistory of the mind*. Thames and Hudson Ltd.

Moro, C. (2015). Material culture: Still 'terra incognita' for psychology today? *Europe's Journal of Psychology*, *11*(2), 172–176. https://doi.org/10.5964/ejop.v11i2.995

Nelson, K. (1973). Some evidence for the cognitive primacy of categorization and its functional basis. *Merrill-Palmer Quarterly of Behavior and Development*, *19*(1), 21–39.

Nomikou, I., Leonardi, G., Rohlfing, K. J., & Rączaszek-Leonardi, J. (2016). Constructing interaction: The development of gaze dynamics: Development of gaze dynamics in interaction. *Infant and Child Development*, *25*(3), 277–295. https://doi.org/10.1002/icd.1975

Nonaka, T., & Goldfield, E. C. (2018). Mother-infant interaction in the emergence of a tool-using skill at mealtime: A process of affordance selection. *Ecological Psychology*, *30*(3), 278–298. https://doi.org/10.1080/10407413.2018.1438199

Nonaka, T., & Stoffregen, T. A. (2020). Social interaction in the emergence of toddler's mealtime spoon use. *Developmental Psychobiology*, *62*(8), 1124–1133. https://doi.org/10.1002/dev.21978

Oakes, L. M. (2008). Categorization skills and concepts. In M. M. Haith & J. B. Benson (Eds.), *Encyclopedia of infant and early childhood development* (pp. 249–259). Academic Press/Elsevier. https://doi.org/10.1016/B978-012370877-9.00043-8

Oakley, K. (1950/1972). *Man the tool-maker* (6th ed.). Trustees of the British Museum.

Okumura, Y., Kanakogi, Y., Kobayashi, T., & Itakura, S. (2020). Ostension affects infant learning more than attention. *Cognition*, *195*, 104082. https://doi.org/10.1016/j.cognition.2019.104082

Pellegrini, A. D., & Hou, Y. (2011). The development of preschool children's (Homo sapiens) uses of objects and their role in peer group centrality. *Journal of Comparative Psychology*, *125*(2), 239–245. https://doi.org/10.1037/a0023046

Rachwani, J., Kaplan, B. E., Tamis-LeMonda, C. S., & Adolph, K. E. (2020). Children's use of everyday artifacts: Learning the hidden affordance of zipping. *Developmental Psychobiology*, *63*(4), 793–799. https://doi.org/10.1002/dev.22049

R Core Team. (2020). *R: A language and environment for statistical computing*. [Computer Software]. R Foundation for Statistical Computing. https://www.R-project.org/

Riede, F., Walsh, M. J., Nowell, A., Langley, M. C., & Johannsen, N. N. (2021). Children and innovation: Play, play objects and object play in cultural evolution. *Evolutionary Human Sciences*, *3*, e11. https://doi.org/10.1017/ehs.2021.7

Rietveld, E., & Kiverstein, J. (2014). A rich landscape of affordances. *Ecological Psychology*, *26*(4), 325–352. https://doi.org/10.1080/10407413.2014.958035

Rocissano, L. (1982). The emergence of social conventional behavior: Evidence from early object play. *Social Cognition*, *1*(1), 50–69. https://doi.org/10.1521/soco.1982.1.1.50

Rodríguez, C. (2012). The functional permanence of the object: A product of consensus. In E. Martí & C. Rodríguez (Eds.), *After Piaget* (pp. 123–150). Transaction Publishers.

Rodríguez, C., Basilio, M., Cárdenas, K., Cavalcante, S., Moreno-Núñez, A., Palacios, P., & Yuste, N. (2018). Object pragmatics. In A. Rosa & J. Valsiner (Eds.), *The Cambridge handbook of socio-cultural psychology* (2nd ed., pp. 223–244). Cambridge University Press.

Rodríguez, C., Estrada, L., Moreno-Llanos, I., & de los Reyes, J.-L. (2017). Executive functions and educational actions in an infant school: Private uses and gestures at the end of the first year. *Estudios de Psicología*, *38*(2), 385–423. https://doi.org/10.1080/02109395.2017.1305061

Rodríguez, C., & Moreno-Llanos, I. (2020). A pragmatic turn in the study of early executive functions by object use and gestures. A case study from 8 to 17 months of age at a nursery school. *Integrative Psychological and Behavioral Science*. https://doi.org/10.1007/s12124-020-09578-5

Rossmanith, N., Costall, A., Reichelt, A. F., LÃ³pez, B., & Reddy, V. (2014). Jointly structuring triadic spaces of meaning and action: Book sharing from 3 months on. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01390

Russell, V. L. (2021). emmeans: Estimated marginal means, aka least-squares means. R package version 1.5.4. https://CRAN.R-project.org/package=emmeans

Schatz, J. L., Suarez-Rivera, C., Kaplan, B. E., & Tamis-LeMonda, C. S. (2022). Infants' object interactions are long and complex during everyday joint engagement. *Developmental Science*, *25*(4). https://doi.org/10.1111/desc.13239

Singmann, H., & Kellen, D. (2019). An introduction to mixed models for experimental psychology. In D. Spieler & E. Schumacher (Eds.), *New methods in cognitive psychology* (1st ed., pp. 4–31). Psychology Press.

Sinha, C. (2009). Objects in a storied world. *Journal of Consciousness Studies*, *16*(6–8), 167–190.

Suarez-Rivera, C., Schatz, J. L., Herzberg, O., & Tamis-LeMonda, C. S. (2022). Joint engagement in the home environment is frequent, multimodal, timely, and structured. *Infancy*, *27*(2), 232–254. https://doi.org/10.1111/infa.12446

Tomasello, M. (2019). *Becoming human*. Harvard University Press.

Uzgiris, I. (1977). Plasticity and structure. In I. Uzgiris & F. Weizmann (Eds.), *The structuring of experience* (pp. 91–110). Plenum Press.

Vauclair, J., & Bard, K. A. (1983). Development of manipulations with objects in ape and human infants. *Journal of Human Evolution*, *12*(7), 631–645. https://doi.org/10.1016/S0047-2484(83)80003-7

Vygotsky, L. S. (1934/2008). *Thought and language*. The MIT Press.

Walker, E. A., Redfern, A., & Oleson, J. J. (2019). Linear mixed-model analysis to examine longitudinal trajectories in vocabulary depth and breadth in children who are hard of hearing. *Journal of Speech, Language, and Hearing Research*, *62*(3), 525–542. https://doi.org/10.1044/2018_JSLHR-L-ASTM-18-0250

Wertsch, J. (1998). *Mind as action*. Oxford University Press.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., & Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Wynberg, E. R., Boland, A., Raijmakers, M. E. J., & van der Veen, C. (2022). Towards a comprehensive view of object-oriented play. *Educational Psychology Review*, *34*(1), 197–228. https://doi.org/10.1007/s10648-021-09608-7

Xu, T. L., de Barbaro, K., Abney, D. H., & Cox, R. F. A. (2020). Finding structure in time: Visualizing and analyzing behavioral time series. *Frontiers in Psychology*, *11*, 1457. https://doi.org/10.3389/fpsyg.2020.01457

Yu, C., & Smith, L. B. (2013). Joint attention without gaze following: Human infants and their parents coordinate visual attention to objects through eye-hand coordination. *PLoS ONE*, *8*(11), e79659. https://doi.org/10.1371/journal.pone.0079659

Yu, C., & Smith, L. B. (2017). Hand-eye coordination predicts joint attention. *Child Development*, *88*(6), 2060–2078. https://doi.org/10.1111/cdev.12730

Zelazo, P. R., & Kearsley, R. B. (1980). The emergence of functional play in infants: Evidence for a major cognitive transition. *Journal of Applied Developmental Psychology*, *1*(2), 95–117. https://doi.org/10.1016/0193-3973(80)90002-7

Zukow, P. G. (1986). The relationship between interaction with the caregiver and the emergence of play activities during the one-word period. *British Journal of Developmental Psychology*, *4*(3), 223–234. https://doi.org/10.1111/j.2044-835X.1986.tb01014.x

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