

# Motion tracking of parents' infant- versus adult-directed actions reveals general and action-specific modulations

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## Abstract

Parents tend to modulate their movements when demonstrating actions to their infants. Thus far, these modulations have primarily been quantified by human raters and for entire interactions, thereby possibly overlooking the intricacy of such demonstrations. Using optical motion tracking, the precise modulations of parents' infant-directed actions were quantified and compared to adult-directed actions and between action types. Parents demonstrated four novel objects to their 14-month-old infants and adult confederates. Each object required a specific action to produce a unique effect (e.g. rattling). Parents were asked to demonstrate an object at least once before passing it to their demonstration partner, and they were subsequently free to exchange the object as often as desired. Infants' success at producing the objects' action-effects was coded during the demonstration session and their memory of the action-effects was tested after a several-minute delay. Indicating general modulations across actions, parents repeated demonstrations more often, performed the actions in closer proximity and demonstrated action-effects for longer when interacting with their infant compared to the adults. Meanwhile, modulations of movement size and velocity were specific to certain action-effect pairs. Furthermore, a 'just right' modulation of proximity was detected, since infants' learning, memory, and parents' prior evaluations of their infants' motor abilities, were related to demonstrations that were performed neither too far from nor too close to the infants. Together, these findings indicate that infant-directed action modulations are not solely overall exaggerations but are dependent upon the characteristics of the to-be learned actions, their effects, and the infant learners.

## KEYWORDS

action learning, infancy, infant-directed actions, kinematics, motion tracking, motionese

## 1 | INTRODUCTION

While observing others, infants are faced with a noisy, continuous flow of actions and effects. Learning from this rich stream of information is complicated. Luckily, it seems parents provide their

infants with a little help by demonstrating actions in a modulated manner (Brand, Baldwin, & Ashburn, 2002). Here, we extend previous research on such infant-directed actions (IDAs), by using motion tracking to precisely quantify *how* parents adjust their movements.

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The first evidence that parents modulate their behaviour when demonstrating actions to their infants as compared to adults came from work by Brand and colleagues (2002). In their study, mothers were video-recorded while demonstrating a series of objects with several interesting features to either their own infant or a familiar adult. Third-party coders judged these interactions offline on eight dimensions. Overall, coders evaluated the IDAs higher than the adult-directed actions (ADAs) on six dimensions, including four which pertained to the nature of the mothers' movements (i.e. proximity of the demonstration, range of motion, repetitiveness and simplification; Brand et al., 2002). This pattern of results was later replicated in a within-participants design with both mothers and fathers (Rutherford & Przednowek, 2012).

These rating-based findings were followed by several endeavours to further quantify IDA characteristics. In one study, the video data from the 2002 study were recoded to investigate structural differences between IDAs and ADAs. Parents showed fewer functions at a time and exchanged toys more often with infants than adults (Brand, Shallcross, Sabatos, & Massie, 2007). In another approach, action demonstrations of ten mothers and fathers were analysed using image processing of video-recorded demonstrations. While demonstrating cup stacking, a repetitive action, parents increased the duration of pausing at the cups' final locations, and the length of the motion paths for infants compared to adults (Rohlfing, Fritsch, Wrede, & Jungmann, 2006). These investigations suggest that the observed differences between IDA and ADA are instantiated in quantifiable modulations in parents' demonstration patterns.

Brand and colleagues (2002) paralleled these action modulations to what is often referred to as 'motherese' or 'parentese', namely the modulations found in infant-directed speech (IDS; Ferguson, 1964; Fernald et al., 1989). Like the documented benefits of IDS for language learning (e.g. Ferguson, 1964; Fernald et al., 1989; Golinkoff, Can, Soderstrom, & Hirsh-Pasek, 2015; Saint-Georges et al., 2013; Spinelli, Fasolo, & Mesman, 2017), they proposed that IDA, dubbed 'motionese', might facilitate action learning by enhancing attention to actions (Brand & Shallcross, 2008), highlighting units within the flow of motion (Brand et al., 2009), and emphasizing action functions (Brand et al., 2002, 2009).

Limited evidence suggests that the modulations of the motions may contribute to such learning benefits. For example, Koterba and Iverson (2009) found that infants whose parents were instructed to demonstrate actions using high amplitudes, many repetitions, or both, looked longer at the demonstrations than a still display. Additionally, many repetitions lead to different types of object exploration by the infants than fewer repetitions (Koterba & Iverson, 2009). In another study, 2-year-olds who were shown actions enacted by the experimenter in an IDA-like manner (e.g. larger range of motion) imitated more target actions than 2-year-olds who saw ADA-like demonstrations (Williamson & Brand, 2014). Hence, this work suggests that action modulations might facilitate action learning, though the enacted (as opposed to natural) IDAs limit the interpretability and specificity of these findings.

## Research Highlights

- Parents' infant- and adult-directed demonstrations of four novel objects with opaque action-effects were recorded using optical motion tracking.
- For all objects, parents demonstrated actions closer and showed effects longer when interacting with their infants compared to adult partners.
- Specific to objects, auditory-effect actions were performed more slowly, and for two of the actions parents made larger movements for their infants than for adults.
- The proximity of demonstrations revealed a 'just right' modulation, with infants learning better from actions performed closer than adult demonstrations but also not too close.

Taken together, parents modulate the content and likely also the movement characteristics of demonstrations when interacting with their infants. However, whether and what infants can learn about the actions from motionese is unclear, largely because we do not know precisely *how* parents modulate their actions. In this study, we set out to quantify parents' action modulations in detail and to explore the effects on infants' learning and memory of action-effect pairs. To this end, parents and their 14-month-olds were invited to the laboratory for a motion-tracking experiment. Parents demonstrated four novel, functionally opaque objects designed for this study, each requiring a specific action to produce a unique effect (e.g. twisting an object to produce a sound), to their own infant and to two adults. We investigated three aims, namely: the primary aim (see Parent Kinematics) of our study was to quantify motionese across and within different actions, while our explorative second (see Learning and Memory) and third aims (see Motor Evaluations) of examining learning effects and the influence of parents' prior beliefs about their infants' action skills serve as starting grounds for future research.

## 1.1 | Parent kinematics

Our first aim was to identify which precise modulations parents make in IDAs compared to ADAs as measured with motion tracking. Initial work on motionese utilized human ratings of entire interactions. Though providing the crucial first evidence for motionese, this method is arguably limited because raters cannot easily focus on only one measure at a time, and might overlook important modulations on an action-level due to the full-interaction scope. Another line of work has successfully used image processing (Nagai & Rohlfing, 2009; Rohlfing et al., 2006), but, like related work on the structural characteristics of motionese (Brand et al., 2007; Meyer, Hard, Brand, McGarvey, & Baldwin, 2011), these cup-stacking studies were not designed to capture modulations specific to instructing novel movements. Hence, this study focused on capturing parents' kinematic modulations of their action demonstrations. The

term kinematics is used to refer to the motion features of parents' movements measured through motion tracking; we investigated 3D distance covered, velocity, proximity and effect duration, as well as the number of times parents repeated object demonstrations. Overall, patterns were expected to reflect those of past studies, in which IDAs have been larger (3D distance covered), closer (proximity), more repetitive (Brand et al., 2002, 2009), slower (velocity; Rutherford & Przednowek, 2012) and have displayed action-effects for longer (effect duration; Rohlfing et al., 2006). Parent kinematics were further examined within two types of comparisons, action-specific versus general modulations and infant versus adult-directed actions.

### 1.1.1 | Action-specific versus general modulations

We further expected that while some modulations might be general, occurring across different actions, certain enhancements might reflect specific aspects of the action-effect pairs. Since past work has not directly compared different types of actions, it could be the case that disparities in those findings stem from averaging over objects or entire interactions. For example, Brand and colleagues (2002) did not find evidence for differences in 'rate' (coded as very slow to very fast), while in their replication study, Rutherford and Przednowek (2012) found IDAs to be slower than ADAs.

### 1.1.2 | Infant versus naïve adult

Since the objects used in past studies were not strictly novel (e.g. stacking cups; Rohlfing et al., 2006), though arguably unusual (e.g. suction cup grippers; Brand et al., 2002), differences between ADAs and IDAs might have reflected parents' evaluations of their partners' object knowledge (Brand et al., 2002). Indeed, recipient design research shows that adults modulate kinematics when interacting with naïve joint action partners (Sacheli, Tidoni, Pavone, Aglioti, & Candidi, 2013; Vesper & Richardson, 2014; Vesper, Schmitz, & Knoblich, 2017). Such findings parallel those in the language domain, in which adults have been found to make IDS-like adjustments when interacting with naïve listeners (e.g. non-native listeners; Smiljanić & Bradlow, 2009; Smith, 2007). Hence, in this study we had parents demonstrate the objects not only to a knowledgeable adult (i.e. the experimenter), but also to an adult whom they were told was naïve to the objects. In this manner, we could test for differences between infant and naïve-adult demonstrations, which would reflect parents' consideration of learners' characteristics beyond their familiarity with the object, such as motor and cognitive development.

## 1.2 | Learning and memory

The second aim was to explore how motionese affects infants' learning and memory of actions. Whereas our setup was optimized for quantifying parents' movements, parents were free to exchange the objects with their partners following at least one demonstration.

This allowed us to code infants' action attempts, and subsequently compare parents' kinematics-preceding infants' successful attempts to the kinematics-preceding failed attempts to explore which modulations facilitate action learning. Furthermore, after a delay, infants' memory of the action-effect pairs was tested and the relation to parents' overall kinematics was examined. Previous work has typically investigated either parents' modulations or infants' learning from enacted or video-taped IDAs, but they have infrequently been measured within the same setting (though see for an exception using cup stacking Fukuyama et al., 2015). Hence, it is unclear whether and how natural parental demonstrations of novel objects benefit infant learners.

## 1.3 | Motor evaluations

The third aim was to explore how parents' prior beliefs about their infants' motor skills influenced their IDAs. Since motionese is thought to facilitate learning (Brand et al., 2002) and because adults adjust their behaviours to their audience (Vesper et al., 2017), it could be expected that IDAs are dependent on the extent to which the demonstrator thinks their infant needs help with the demonstrated action. Before coming to the laboratory, parents rated their infants' overall motor abilities and how readily they learn about new toys. We hypothesized that parents who believed their infant to be less motorically skilled would modulate their IDAs more than parents who thought their infants to be more motorically proficient.

# 2 | METHODS

## 2.1 | Participants

Forty-five parents participated in this study with their 14-month-olds. The data of five parent-infant dyads were excluded from the analyses: one infant was excluded due to parent-reported prematurity, two infants did not complete the session, one parent let the infant play with the objects before demonstration, and the data of one dyad were lost due to a corrupt file. The final sample consisted of 40 parent-infant dyads, of which 37 included mothers. Infants were on average 14.3 months old (range: 13.5–15.2 months; 19 girls).

Participants were recruited from a database of volunteer families representative of the middle-sized Western European city in which the research was conducted. The available parent was invited to the laboratory irrespective of gender, as past work has shown that both mothers and fathers modulate their action demonstrations (Rutherford & Przednowek, 2012). All parents gave separate signed informed consent for their own and their infant's participation. Parent-infant dyads were thanked for their participation with either a children's book or 10 euros. This line of research was approved by the local social science faculty's research ethics board and was carried out in accordance with the Declaration of Helsinki.

## 2.2 | Materials

### 2.2.1 | Objects and their effects

A set of four cylindrical objects was designed and 3D-printed for this study. Each object was identifiable only by its colour and could produce a single visual or auditory action-effect when operated (see Figure 1 for objects and effects). Due to the similarity in the objects' appearance, the action-effects were opaque to someone unfamiliar with them. The objects were chosen to differ in difficulty, with easier objects included to ensure that infants were able to operate at least some of the objects, and more difficult objects included to be sure of requiring repeated parental demonstrations. Parents were instructed on how to operate the objects via an instruction card to avoid any potential influence of an overt demonstration by the experimenter.

### 2.2.2 | Motor evaluation





Before coming to the laboratory, parents were asked to rate their infants' motor abilities using a 5-point scale (bad to very good) designed for this study. Parents rated their infants' abilities to (1) learn how to use new toys and to (2) understand how to use new toys, as well as their infants' (3) general motor abilities. The questions were broad in scope in order to capture parents' subjective beliefs about their infants' motor abilities.

### 2.2.3 | Motion tracking

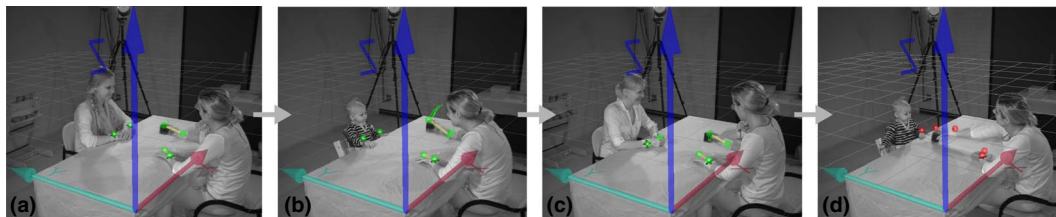
A Qualisys Oqus 5 + system with seven motion cameras and one video camera was used to record parents' movements. Parents wore four markers attached to elastic bands, one atop the first joint of either index finger and one on the dorsal side of either wrist (Figure 2). The demonstration partners wore similar wrist markers and smaller wrist markers were put on infants if they permitted. This was done in interest of the cover story (see Procedure 3.3), and only the data from parents' index finger markers were used in the analyses.

## 2.3 | Design

A repeated-measures (RM) design was employed. Each parent always demonstrated the objects first to one of the two adult partners (naïve or knowledgeable; Figure 2a), second to their infant (Figure 2b) and third to the other adult partner (Figure 2c). The study was concluded with the infant memory test (Figure 2d). The sandwiching of the infant demonstration between the two demonstrations to adults ensured a fairly consistent delay period between the infant demonstration, during which infants' learning was measured, and the infant memory test. The order of the adult demonstrations (i.e. first knowledgeable, third naïve or vice versa) was counterbalanced. The order in which parents were asked to present the objects was counterbalanced across participants; hence the same order of

<i>Object</i>				
<i>Action</i>	shake	twist	press	pull
<i>Effect and Type</i>	rattle 🗣️	"kggrrr" 🗣️	light 👁️	separated halves 👁️
<i>Parent Instructions</i>	shake → sound	turn two halves → sound	press on top → light	take apart two halves

**FIGURE 1** The four objects and their characteristics. Each object was identifiable by its colour and allowed for a specific action to produce its effect. Parent instructions are depicted as in the experiment



**FIGURE 2** Experimental design and motion tracking setup. Parents demonstrated the objects to the knowledgeable adult (a), then to their own infant (b) and lastly to the naïve adult (c). Infants' learning was coded during the infant-directed demonstration. Infants' memory was scored during the memory test at the end (d). The order of knowledgeable and naïve demonstrations was counterbalanced across participants. Parents wore index finger and wrist markers and demonstration partners wore wrist markers (green dots; a–c). The pink, cyan and blue lines depict the x, y and z axes, respectively, of the motion tracked space

objects was followed for all three of a parent's demonstrations and for the memory test.

## 2.4 | Procedure

Two experimenters ran the study. The main experimenter provided the instructions and served as the knowledgeable adult partner. The second experimenter played with the infant on a mat behind the parent to prevent exposing the infant to the objects during the adult demonstrations.

At the start of the experiment, we told the parents the cover story that the goal of the study was to investigate differences in the ways infants and adults learned about new objects. This was to direct the focus away from parents' own actions. Parents were shown the markers and told to use their hands as they normally would. They were then asked to read the instruction cards (Figure 1) and try each object. Parents were informed about the three demonstration sessions and memory test. They were asked to interact with their partners as naturally as possible and were free to speak to their partners. They were instructed to demonstrate the object at least once, before passing it on to their partner so the partner could try. Parents were subsequently free to exchange the object back-and-forth with their partner as often as they liked. Throughout the experiment, parents were seated at one side of a table, with their partner seated directly across from them (Figure 2). The objects were in arm's reach of the parents, in the right-hand corner of the table. They were placed in a tray with a high back to keep them hidden from the demonstration partners' view.

At the start of each demonstration session, the experimenter repeated the instructions. Before the naïve adult demonstration, the experimenter picked up the supposed naïve adult participant (actually a confederate) in the adjacent room. The naïve adult was introduced to the second experimenter and parent and given instructions about the task and markers. The naïve and knowledgeable adults had been trained to perform the actions in the same efficient manner so as not to influence parents' subsequent demonstrations, but the naïve adult responded to parents' demonstrations by making surprised remarks, such as 'oh ok!' and 'aha!'

At the start of the memory test, parents were instructed to hand the object to their infant without demonstrating the action and without verbally explaining how to perform the action. Once the infant was done acting on the object, or after 30 s, the parent was asked to provide the next object. At the end of the experiment, parents were informed about the goal of investigating the differences between IDAs and ADAs.

## 2.5 | Measures

### 2.5.1 | Parent action coding

To be able to calculate parents' action kinematics, start and end times of parents' actions were coded offline. Coding was performed in Qualisys Track Manager (Version 2.11) and the segmented action coordinates were exported to MATLAB in which the kinematic measures

were calculated. The two auditory-effect objects (i.e. the grey-shake and orange-twist objects) were coded from the first frame in which the movement was initiated until the last frame of movement. Pauses shorter than one second were included in a single action, while longer pauses defined a new execution of the action. Since moving these objects caused the sounds to occur, this start-to-finish coding was used to measure how long action effects were demonstrated as well as the kinematic measures pertaining to the movements themselves.

The two visual-effect objects (i.e. the red-press and yellow-pull objects) were coded in two phases. The first phases concerned the actions required to create the visual-effects and were hence used to calculate the kinematic measures. The second phases concerned the duration of the resulting effects. These two phases were coded separately for these objects because the visual action-effects were maintained so long as there was no movement (e.g. keeping the finger on the red toy kept the light on). For the red-press object, the first phase started when the approach movement towards the object started and ended once the finger made contact with the top of the object. The second phase was coded from the first frame in which the finger made contact to the last frame of contact with the top of the object, that is, the duration for which the light was visible. The first phase of the yellow-pull object consisted of the pulling action and was coded from the last frame before the two parts were separated to the first frame in which the two halves were maximally apart. The second phase was coded as starting when the halves were maximally apart until the last frame before the movement to reunite the halves was initiated, thus corresponding with the visual-effect duration of the two halves being apart.

### 2.5.2 | Parent kinematics

The first phases of the visual-effect objects' actions and the full actions of the auditory-effect objects were used to calculate the 3D distance covered, velocity, proximity and repetitions. The second phases of the visual-effect objects' actions and the full actions of the auditory-effect objects were used to calculate the effect duration.

#### 3D distance covered

The total distance covered during an action was calculated by summing the distance between all successive time points using equation (1), where the coordinates are denoted with (x, y, z) and time points of measurement as *i*. 3D distance covered was measured in mm.

$$\sum_{i=0}^{i_{\max}-1} \sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2 + (z_{i+1}-z_i)^2} \quad (1)$$

#### Velocity

Average velocity of each action was calculated as the change in position divided by the total time, *T*, equation (2). Velocity was measured in mm/s.

$$\frac{1}{T} \sum_{i=0}^{i_{\max}-1} \sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2 + (z_{i+1}-z_i)^2} \quad (2)$$

### Proximity

The one-dimensional distance between parents' index fingers and the parent's edge of the table was averaged per action. The table was 780 mm wide. Thus, a proximity measure close to 0 indicates that the parent's hands were near the edge of their side of the table, while a proximity measure approaching 780 mm indicates the parent's hands were at their demonstration partner's edge of the table.

### Effect duration

How long demonstration partners were shown action-effects was calculated in seconds.

### Repetitions

The number of times a parent demonstrated an object was tallied. The above kinematic measures were averaged across repetitions, where applicable, such that for each parent, for each object, for each demonstration partner, a single value of the kinematic measure was attained.

## 2.5.3 | Infant action coding

Infants' actions were coded offline using Qualisys Track Manager and video recordings from two corner cameras and a central microphone (Noldus Information Technology, Media Recorder, Version 2.5).

### Learning

Since parents were free to exchange the objects back-and-forth, infants' abilities to produce the action-effects during the demonstration session could be coded as a measure of learning. Every attempt was coded as either a success or a failure. Successes were coded if the infant was able to produce the action-effect with the correct movement. Failed attempts were coded when the infant handled the object but was unable to elicit the effect, hence including instances when infants attempted the correct movements but fell short of achieving the effect.

Two measures were gleaned from this coding. First, an overall score of learning was obtained by calculating the infant's ratio of successes to total number of attempts. Second, parents' kinematic measures were recalculated separately for demonstrations preceding infants' successes and preceding infants' failures. These kinematics-preceding-learning measures hence comprised a subset of the demonstrations included in the main kinematic measures but did not necessarily overlap fully. For example, if a parent demonstrated an object, passed the object to the infant and subsequently demonstrated the object again before putting it back on the object tray, the main kinematic measure would be an average of both instances while the learning kinematic measure would only consider the demonstration directly preceding the infant's attempt.

The grey-shake learning data of two infants were missing: one infant did not receive the object and one infant did not manipulate the object. Three infants' learning data of the orange-twist object

were missing: one infant performed the action together with their parent and two infants did not manipulate the object.

### Memory

Infants' memory of object-effect pairs was coded in the same binary way, successes and failures. Only first attempts were considered because through handling the objects again, infants might have accidentally rediscovered the actions and effects.

The data of two infants were excluded because they had watched an adult-demonstration session and one infant did not participate in the memory test. Additionally, the memory data of one infant on the grey-shake object were excluded because the infant had played with the object in between the demonstration and the memory test, and another infants' orange-twist memory score was excluded because the parent demonstrated the object at the start of the memory test.

## 2.5.4 | Motor evaluation groups

The three motor ability evaluation questions were averaged per parent. Although the Likert scale had ranged from 1 to 5, averages were between 3.3 and 4.6. Hence, two groups were defined, namely: parents who rated their infants' motor abilities at or below the median score (i.e. average motor evaluation group;  $n = 22$ ) and parents who evaluated their infants' motor abilities above the median score (i.e. high-motor evaluation group;  $n = 18$ ).

## 2.6 | Data analyses

### 2.6.1 | Parent kinematics

The first aim, examining differences between IDAs and the two types of ADAs, was addressed with a RM MANOVA. It was conducted with demonstration partner (infant, naïve adult and knowledgeable adult) and object (grey-shake, orange-twist, red-press, yellow-pull) as factors and 3D distance covered, velocity, proximity and effect duration as dependent measures. Multivariate  $F$  ratios were based on Pillai's trace approximation. Upon significant interaction effects, separate RM ANOVAs were used to examine the effects per dependent variable. Univariate  $F$  ratios were estimated using Greenhouse-Geisser corrections. Subsequently, paired samples  $t$ -tests were used to compare demonstration partners per object, per kinematics measure. Two-sided  $p$ -values were controlled for false discovery rate using the Benjamini-Hochberg procedure executed with the MATLAB function `mafdr.m`. This was applied across all comparisons of demonstration partners, objects, and kinematic measures. The data of 31 parents were included in these analyses. The remaining nine parents had at least one missing data point for at least one object for at least one partner's demonstration. Missing data points were caused by parents inadvertently lifting their index fingers from an object and other instances of being unable to use the motion tracking data (e.g. markers being covered).

For all analyses, an alpha level of 0.05 was used and two-sided *p*-values are reported.

The fifth measure of parental demonstrations, the number of repetitions, was neither included in the above analyses nor tested for differences between demonstration partners because nearly all demonstrations to adults were repeated just once. Instead, the repetition counts were descriptively compared between infant- and adult-demonstrations. Additionally, as an exploratory investigation of object differences, only the repetitions of infant demonstrations were compared between objects using a Friedman's test. Following a significant effect, Wilcoxon signed-rank tests were used to compare objects. Bonferroni correction was applied on the two-sided significance values. For consistency, repetition analyses are presented for the same 31 parents whose data were included in the above kinematics analyses. As a control, the repetitions analyses were also performed on all parents' data and the conclusions were unchanged.

## 2.6.2 | Learning

Parental kinematics measures preceding successful attempts of the infants were compared to those preceding unsuccessful attempts. This was analysed in a data-driven manner based on the IDA versus ADA findings of the main parents' kinematics analyses. That is, learning effects were investigated per measure only for the objects in which differences between IDA and ADA were found. Linear fixed-effect models by means of maximum likelihood estimation were used because not all parent-infant dyads contributed to both success and failure cells for all objects. Upon significant effects, Bonferroni-corrected pairwise comparisons based on estimated marginal means were performed. These and subsequent analyses were performed with the full sample, as opposed to the 31 parents of the parental kinematics RM MANOVA, to maximize power.

**TABLE 1** RM ANOVAs per kinematic measure

Kinematics measure	Effect	<i>F</i>	<i>df</i>	<i>p</i>	$\eta p^2$
Distance covered	Demonstration partner	8.75	1.65	0.001	0.23
	Object	136.89	1.43	<0.001	0.82
	Demonstration partner $\times$ object	6.84	2.28	0.001	0.19
Velocity	Demonstration partner	4.21	1.93	0.021	0.12
	Object	124.26	2.28	<0.001	0.81
	Demonstration partner $\times$ object	7.46	4.17	<0.001	0.20
Proximity	Demonstration partner	145.18	1.90	<0.001	0.83
	Object	30.08	2.07	<0.001	0.50
	Demonstration partner $\times$ object	3.56	3.68	0.011	0.11
Effect duration	Demonstration partner	56.85	1.45	<0.001	0.66
	Object	54.32	1.86	<0.001	0.64
	Demonstration Partner $\times$ object	4.46	2.97	0.006	0.13

Note: Greenhouse-Geisser corrected values.

## 2.6.3 | Memory

The group sizes of successful infants and failing infants were grossly unequal for two of the objects (e.g. 2 vs. 33 for the orange-twist object). Hence, the pattern of results was only qualitatively compared to the learning results.

## 2.6.4 | Motor evaluations

Parents' kinematics between the two motor evaluation groups were compared per measure using only the objects that revealed IDA modulations in that measure. RM ANOVAs were performed per kinematic measure with motor ability group as the between-participants factor. Main effects of object were not of interest and hence not reported, but interactions between motor ability group and object were included because of the possibility of finding evaluation effects for specific objects and the exploratory nature of these analyses.

## 3 | RESULTS

### 3.1 | Parent kinematics

The RM MANOVA revealed a significant main effect of demonstration partner, Pillai's trace = 0.946,  $F(8,23) = 50.80$ ,  $p < 0.001$ ,  $\eta p^2 = 0.95$ , a significant main effect of object, Pillai's trace = 0.978,  $F(12,19) = 71.30$ ,  $p < 0.001$ ,  $\eta p^2 = 0.98$ , and a significant interaction between demonstration partner and object on parents' kinematics, Pillai's trace = 0.970,  $F(24,7) = 9.42$ ,  $p = 0.003$ ,  $\eta p^2 = 0.97$ . Subsequently, RM ANOVAs were performed for each kinematic measure. Table 1 presents these test statistics. All main effects and interaction effects were significant.

To discern the specificity of the above effects, the planned pairwise comparisons were conducted (Table S1). Significant effects are

denoted in Figure 3, presenting violin plots with inlaid box plots for each kinematic measure, split by demonstration partner and object.

### 3.1.1 | 3D distance covered

Parents covered significantly more distance while demonstrating the grey-shake object to their infant than to either adult, infant-naïve:  $t(30) = 3.50$ ,  $p = 0.003$ ,  $r = 0.54$ ; infant-knowledgeable:  $t(30) = 3.18$ ,  $p = 0.007$ ,  $r = 0.50$  (Figure 3a). A similar effect was found for the red-press object, infant-knowledgeable:  $t(30) = 3.23$ ,  $p = 0.007$ ,  $r = 0.51$ , but the difference between infant and naïve demonstrations failed to reach significance, infant-naïve:  $t(30) = 1.92$ ,  $p = 0.128$ ,  $r = 0.33$ . No significant differences between naïve and knowledgeable adult demonstrations were found.

### 3.1.2 | Velocity

With respect to the measure of velocity (Figure 3b), parents moved more slowly while demonstrating the two auditory-effect objects to their infant compared to either adult partner, grey-shake: infant-naïve:  $t(30) = 4.88$ ,  $p < 0.001$ ,  $r = 0.67$ ; infant-knowledgeable:  $t(30) = -3.73$ ,  $p = 0.003$ ,  $r = 0.56$ ; orange-twist: infant-naïve:  $t(30) = -5.35$ ,  $p < 0.001$ ,  $r = 0.70$ ; infant-knowledgeable:  $t(30) = -5.04$ ,

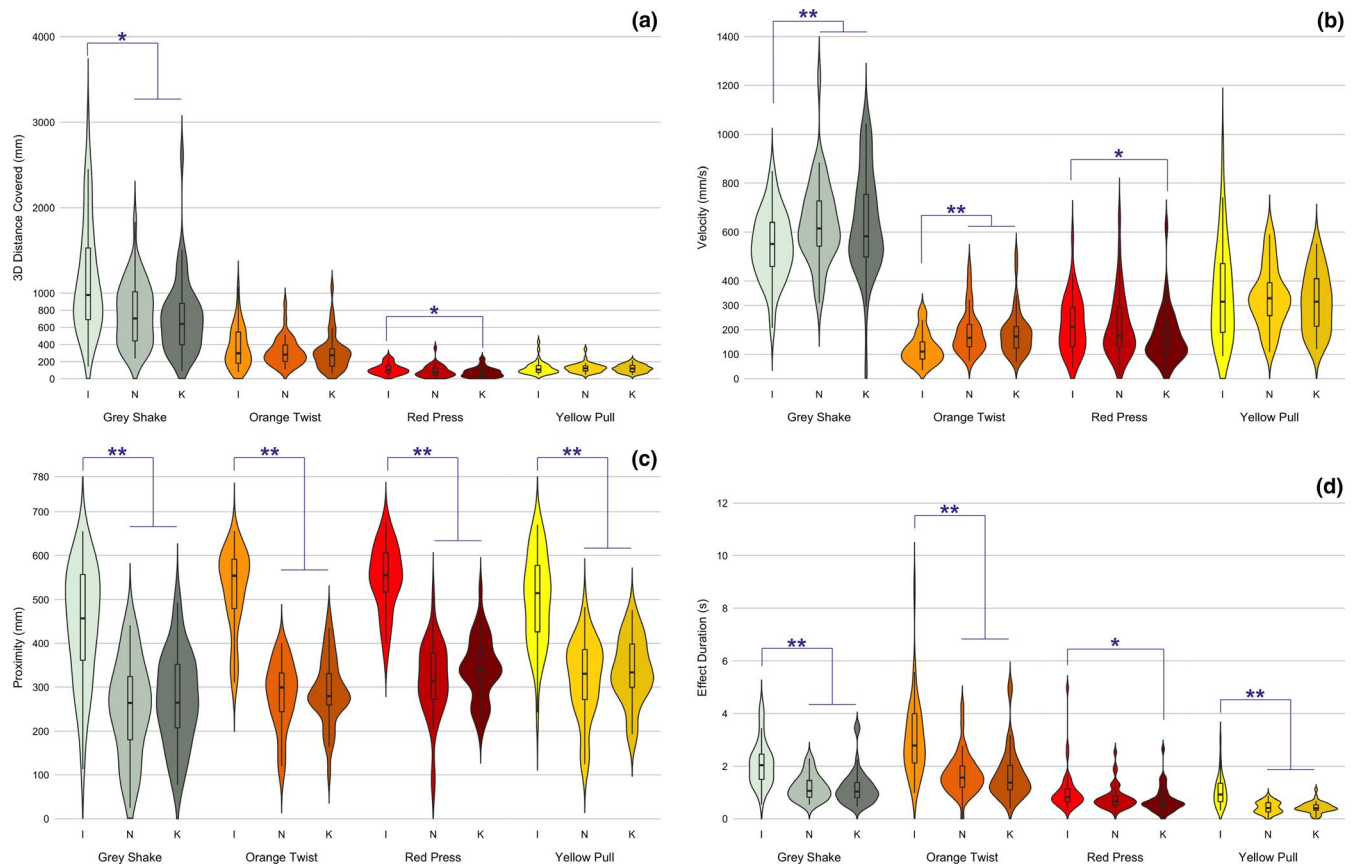
$p < 0.001$ ,  $r = 0.68$ . Contrarily, parents moved towards pressing the red-press object more quickly while demonstrating the object to their infant versus the knowledgeable adult, infant-knowledgeable:  $t(30) = 2.82$ ,  $p = 0.017$ ,  $r = 0.46$ , but the infant and naïve demonstrations did not differ significantly, infant-naïve:  $t(30) = 0.33$ ,  $p = 0.831$ ,  $r = 0.06$ . The velocity measure did not differ significantly between naïve and knowledgeable adult demonstrations for any object.

### 3.1.3 | Proximity

For all objects, parents demonstrated the actions closer to their infant than to either adult partner,  $ps < 0.001$ ;  $rs > 0.8$  (Figure 3c). Naïve and knowledgeable adult demonstrations did not differ significantly in proximity,  $ps > 0.250$ .

### 3.1.4 | Effect duration

Parents showed almost all effects (i.e. grey-shake, orange-twist and yellow-pull object-effects) for longer when demonstrating objects to their infants than to either adult partner,  $ps < 0.001$ ,  $rs > 0.6$  (Figure 3d). Parents demonstrated the red-press object's light-effect to their infant longer than to the knowledgeable adult, infant-knowledgeable:  $t(30) = 2.74$ ,  $p = 0.021$ ,  $r = 0.45$ , but the difference



**FIGURE 3** Parents' Kinematics. Violin plots with inlaid box plots of infant- naïve- and knowledgeable-directed action kinematics: 3D-distance-covered (a), velocity (b), proximity (c), and effect durations (d). Note. I = Infant, N = Naïve adult, K = Knowledgeable adult. \* $p < 0.05$ , \*\* $p < 0.005$



between infant- and naïve-adult demonstrations was not significant, infant-naïve:  $t(30) = 1.89$ ,  $p = 0.132$ ,  $r = 0.33$ . Again, no significant differences were found between naïve and knowledgeable adult demonstrations.

### 3.1.5 | Repetitions

The number of repetitions parents made on average per demonstration partner and per object are reported in Table 2. It is clear that parents repeated demonstrations considerably more often for their infants than they did for the adult-demonstration partners.

Taken together, proximity, effect duration and repetitions were enhanced in IDAs compared to ADAs across objects, while modulations in IDAs as compared to ADAs were object-, and hence, action-specific with respect to the 3D distance covered and the velocity of the movements.

### 3.1.6 | Infant-directed repetitions

The exploratory Friedman's test of the infant-demonstration repetitions per object revealed a significant difference in repetitions across objects,  $\chi^2(3) = 31.89$ ,  $p < 0.001$ . Post-hoc comparisons indicated that the orange-twist object ( $Mdn = 4$ ) was repeated significantly more often than the grey-shake object ( $Mdn = 1$ ),  $z = 2.72$ ,  $p = 0.03$ ,  $r = 0.35$ , and the yellow-pull object ( $Mdn = 2$ ),  $z = 4.04$ ,  $p < 0.005$ ,  $r = 0.51$ . Similarly, the red-press object ( $Mdn = 5$ ) was also repeated significantly more often than both the grey-shake object,  $z = 3.70$ ,  $p < 0.005$ ,  $r = 0.47$ , and the yellow-pull object,  $z = 4.07$ ,  $p < 0.005$ ,  $r = 0.52$ . There were neither significant differences between the orange-twist and red-press objects nor between the grey-shake and yellow-pull objects,  $ps > 0.250$ .

## 3.2 | Learning

Table 3 presents overall success ratios of infants per object. Parents' kinematics split between demonstrations preceding infants' successful and failed attempts are plotted in Figure 4. Modulations in 3D distance covered were found specifically for the grey-shake and red-press objects in the main parents' kinematics analyses, so the learning analysis of this measure was constrained to these two objects. A linear fixed-effect model was performed on 3D distance covered with learning (i.e. preceding successes or failures) and objects as within-participant factors (Figure 4a). There was only a significant main effect of object,  $F(1,86) = 55.52$ ,  $p < 0.001$ , with the grey-shake object demonstrations having unsurprisingly covered

significantly more distance ( $M = 1,172.77$  mm,  $SE = 113.90$ ) than the red-press actions ( $M = 110.73$ ,  $SE = 85.7$ ).

The IDA modulations in velocity were found for the grey-shake, orange-twist, and red-press objects, leading to the inclusion of these three objects in the learning analysis of velocity (Figure 4b). This analysis also revealed only a significant main effect of object,  $F(1,125) = 71.46$ ,  $p < 0.001$ , with grey-shake demonstrations having been faster ( $M = 552.11$  mm/s,  $SE = 26.15$ ) than both other objects,  $ps < 0.001$ , and red-press demonstrations having been faster ( $M = 238.80$  mm/s,  $SE = 19.68$ ) than orange-twist demonstrations ( $M = 133.00$  mm/s,  $SE = 26.24$ ),  $p = 0.005$ .

Since modulations in IDAs versus ADAs were found across objects for the measures of proximity, learning effects of these measures were tested for all objects (Figure 4c). The model of proximity yielded a significant main effect of learning,  $F(1,165) = 7.30$ ,  $p = 0.008$ , with proximity preceding successes ( $M = 485.23$  mm,  $SE = 12.04$ ) being lower than proximity preceding failures ( $M = 542.05$  mm,  $SE = 17.26$ ). There was also the main effect of object,  $F(3,165) = 3.74$ ,  $p = 0.012$ . Pairwise comparisons revealed that the grey-shake object was performed significantly further away from the infant ( $M = 480.72$  mm,  $SE = 20.17$ ) than the red-press object ( $M = 559.11$  mm,  $SE = 15.18$ ),  $p = 0.013$ .

The same analysis was performed on effect duration (Figure 4d), revealing a main effect of learning,  $F(1,172) = 4.19$ ,  $p = 0.042$ , a main effect of object,  $F(3,172) = 39.34$ ,  $p < 0.001$ , and an interaction effect between learning and object,  $F(3,172) = 3.49$ ,  $p = 0.017$ . The interaction effect was followed up with separate iterations of the analysis per object. This revealed a significant learning effect only for the orange-twist object,  $F(1,39) = 7.32$ ,  $p = 0.01$ , with successful attempts of infants having been preceded with significantly longer effect demonstrations ( $M = 4.45$  s,  $SE = 0.52$ ) than failed attempts ( $M = 2.86$  s,  $SE = 0.27$ ). However, this finding should be interpreted with caution due to particularly many missing success cells for the orange-twist object, as can be gleaned from the lower overall success ratios of this object (Table 3).

In summary, learning effects were found for the general measures of proximity and effect duration, though the latter was specific to the orange-twist object, but not for the action-specific modulations of 3D distance covered and velocity.

## 3.3 | Memory

Table 4 shows the number of infants who succeeded and failed on their first attempts to perform the actions during the memory test. Figure 5 presents parents' kinematics during the infant

**TABLE 2** Mean number of repetitions of parent demonstrations per object and demonstration partner

Object	Infant (min-max)	Naïve adult (min-max)	Knowledgeable adult (Min-Max)
Grey-shake	2.23 (1-7)	1 (1-1)	1 (1-2)
Orange-twist	4.06 (1-16)	1 (1-1)	1.1 (1-2)
Red-press	5.58 (1-19)	1.35 (1-3)	1.29 (1-3)
Yellow-pull	1.77 (1-5)	1.01 (1-2)	1.06 (1-2)

demonstration session split on whether their infant later succeeded or failed at the memory test. Interestingly, the pattern of overall kinematics between infants succeeding and failing on the memory test (note: between-participants split; Figure 5) descriptively resembles the pattern of learning results, in which parents' kinematics were split preceding their infants' successes and failures *during* the demonstration session (note: within-participants split; Figure 4). For example, lower demonstration proximity went with successful memory test performance, just as lower proximities were related to successful learning (Figure 4c vs. Figure 5c).

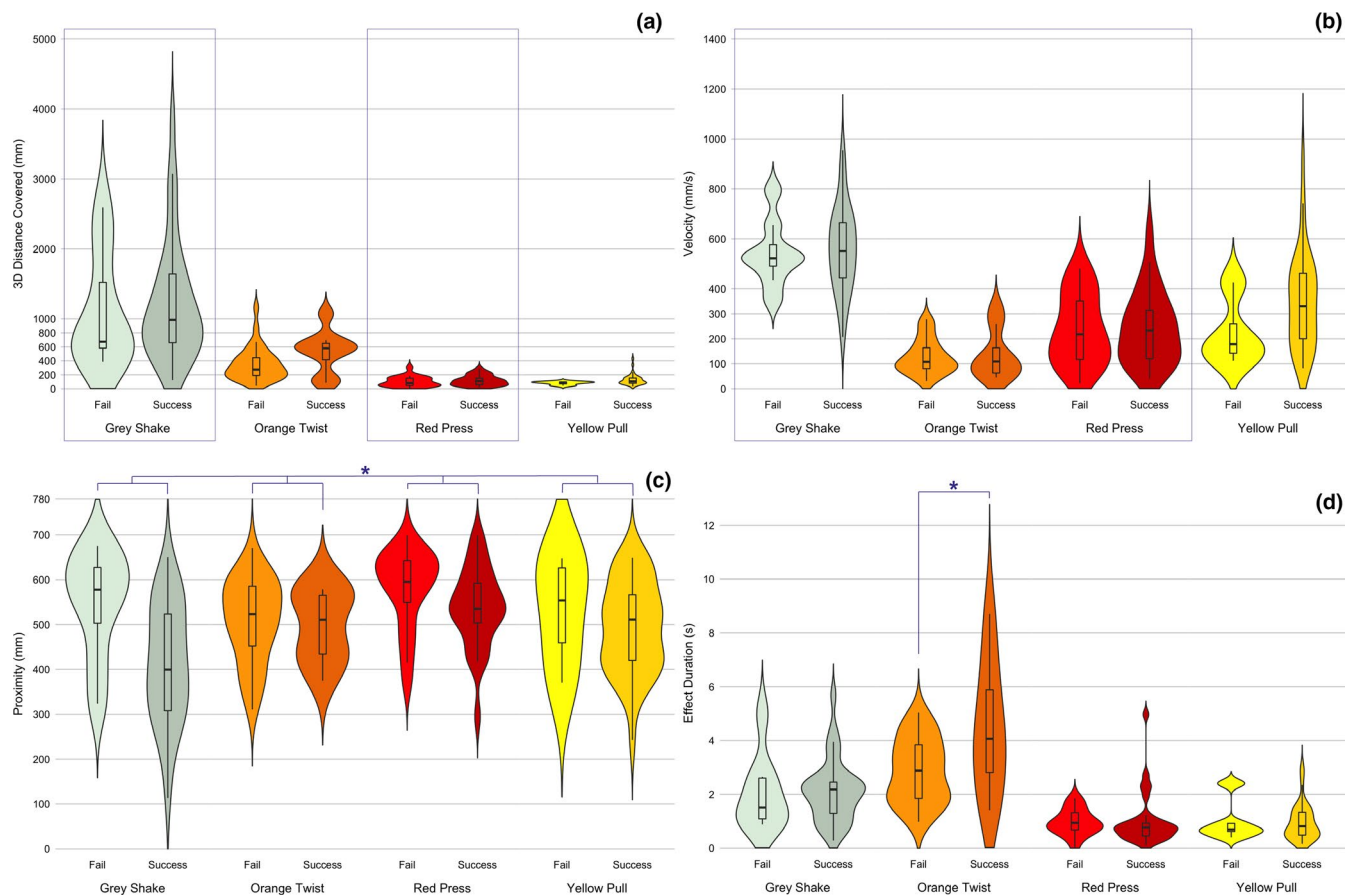
**TABLE 3** Mean success ratios of infants during the learning phase

Object	Mean	SD	Min	Max
Grey-shake	0.64	0.34	0	1
Orange-twist	0.1	0.21	0	0.75
Red-press	0.52	0.4	0	1
Yellow-pull	0.62	0.28	0	1

### 3.4 | Motor evaluations

A RM ANOVA on 3D distance covered was performed including the grey-shake and red-press objects and with the between-participants factor of motor evaluation groups (Figure 6a). A main effect of motor evaluation group was found at marginal significance,  $F(1) = 2.89$ ,  $p = 0.098$ ,  $\eta p^2 = 0.074$ , with the average-motor ability raters covering more distance ( $M = 728.27$ ,  $SE = 9.74$ ) than the high-motor evaluation group ( $M = 545.55$ ,  $SE = 81.78$ ). The RM ANOVA on velocity was performed including the grey-shake, orange-twist and red-press objects, but neither revealed a significant main effect of motor evaluation, nor an interaction with object (Figure 6b).

As with the learning analyses, the RM ANOVAs on proximity and on effect duration were performed including all objects. A significant main effect of motor evaluation was found on proximity,  $F(1) = 6.23$ ,  $p = 0.018$ , with the high-motor evaluation group parents performing actions closer to their infants ( $M = 542.26$ ,  $SE = 21.43$ ) than the average motor evaluation group ( $M = 473.84$ ,  $SE = 17.1$ ; Figure 6c). The analysis of effect duration did not reveal significant effects of motor evaluation (Figure 6d).



**FIGURE 4** Learning. Violin plots with inlaid box plots of parents' kinematics-preceding infants' failures and successes: 3D-distance-covered (a), velocity (b), proximity (c) and effect durations (d). Note. 3D distance covered: statistical analyses only performed for grey-shake and red-press objects. Velocity: statistical analyses only performed for grey-shake, orange-twist and red-press objects. Main effects of object are not denoted. \* $p < 0.05$

### 3.5 | Exploration of proximity findings

Both the learning and motor evaluation analyses of proximity present what at first glance seem to be counterintuitive results. While parents performed actions significantly closer to their infants than their adult-demonstration partners, closer proximity was related to infants' subsequent failures to perform actions. Additionally, parents who evaluated their infants as being average in motor abilities performed actions further away from their infants than the high-motor evaluations group. These findings together might suggest an optimal proximity for demonstrations, namely closer than for adult demonstrations (Figure 3c) but also not too close to the infant (Figure 4–6c). It could be the case that actions demonstrated slightly further away from the infant afford modulations in other domains, such as the size of the action, because of the infants' visual space. Performing a large action close to the infant

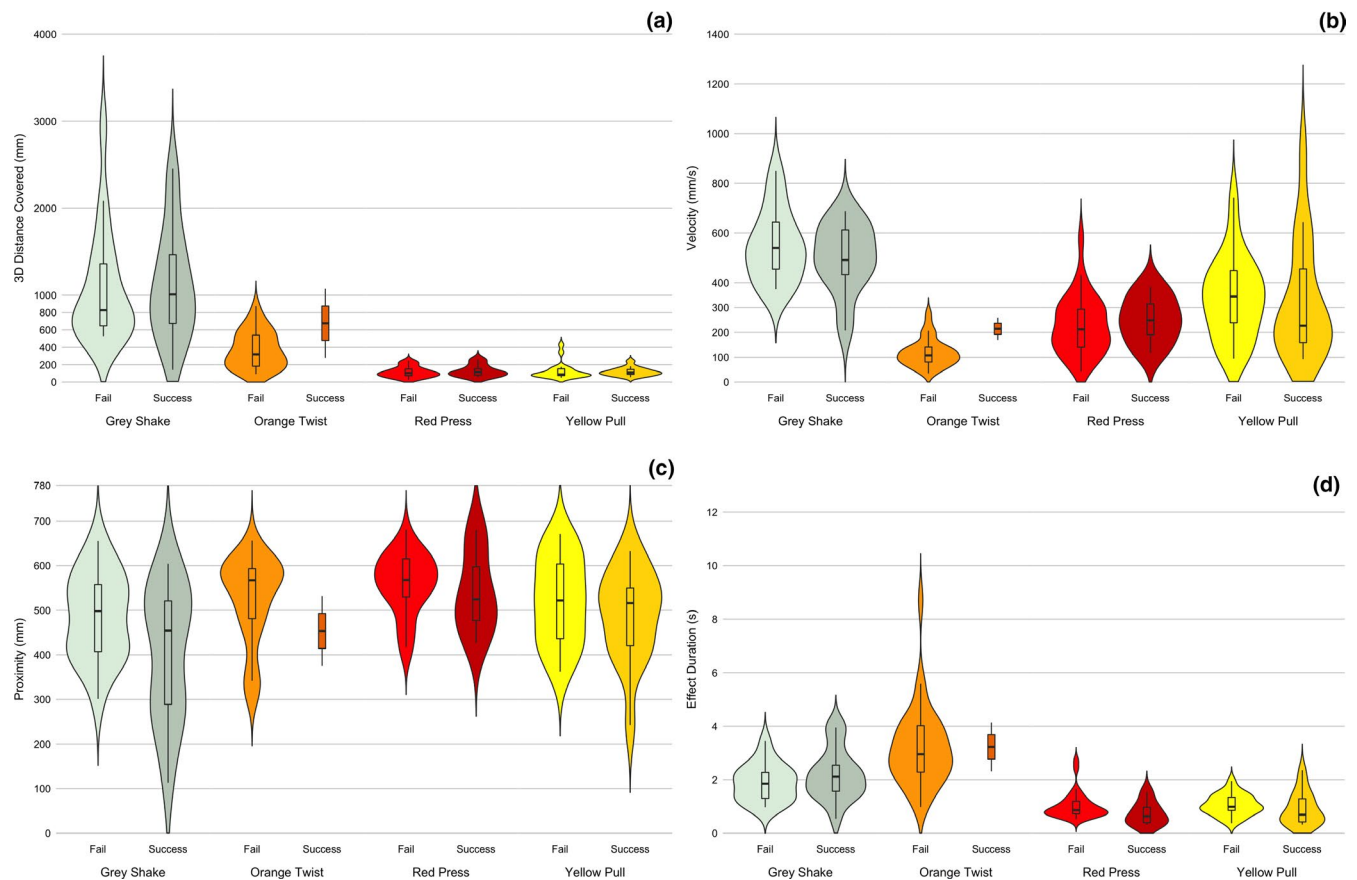
might mean that the outer edges of the action are outside of the infant's visual space, while the same-sized action performed slightly further away from the infant would be completely visible for the infant. This speculation was tested with an exploratory correlation of proximity and 3D distance covered on the grey-shake object, since IDAs were found to be modulated in 3D distance covered for this object as compared to ADAs. Indeed, there was a significant inverse correlation between proximity of parents' IDAs and the 3D distance covered by these demonstrations, Pearson's  $r = -0.42$ ,  $p = 0.007$  (Figure S1).

## 4 | DISCUSSION

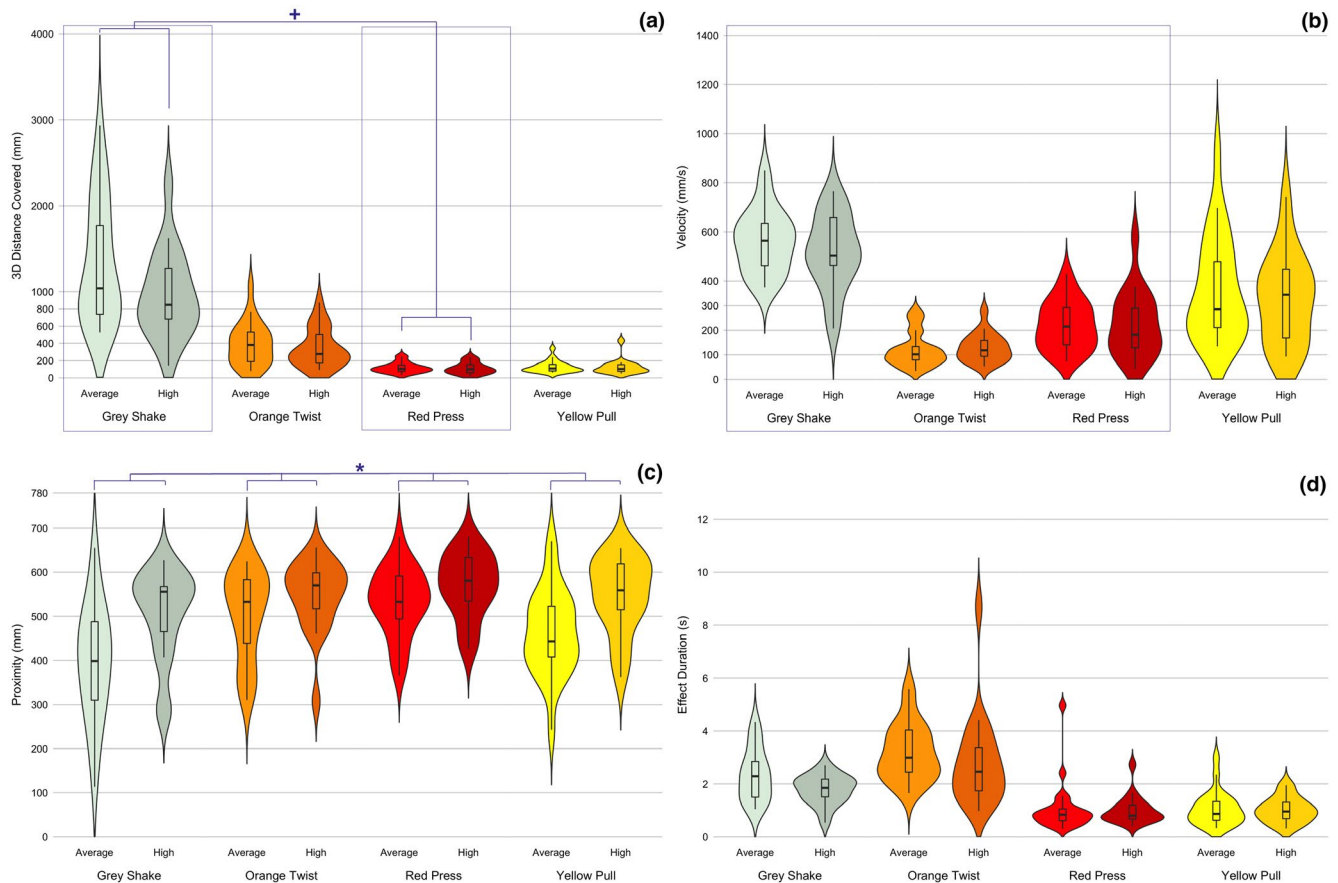
In this study, we precisely quantified parents' IDAs in the context of action-effect demonstrations. We further explored the effects of

**TABLE 4** Numbers and percentages of infants succeeding or failing the memory test

Object	Success <i>n</i> (%)	Failure <i>n</i> (%)	No attempts <i>n</i> (%)	Total <i>n</i>
Grey-shake	16 (44%)	18 (50%)	2 (6%)	36
Orange-twist	2 (6%)	33 (92%)	1 (2%)	36
Red-press	7 (19%)	30 (81%)	0	37
Yellow-pull	15 (40%)	22 (60%)	0	37



**FIGURE 5** Memory. Violin plots with inlaid box plots of parents' overall kinematics for infants who failed and succeeded at memory test: 3D-distance-covered (a), velocity (b), proximity (c) and effect durations (d). Note.  $n = 2$  for orange-twist object success, and  $n = 7$  for red-press object success. No statistical analyses were performed on this data



**FIGURE 6** Motor Evaluations. Violin plots with inlaid box plots of parents' overall kinematics for parents who rated their infants' motor abilities as average and as high: 3D-distance-covered (a), velocity (b), proximity (c) and effect durations (d). Note. 3D distance covered: statistical analyses only performed for grey-shake and red-press objects. Velocity: statistical analyses only performed for grey-shake, orange-twist, and red-press objects. \* $p < 0.05$ , + $p < 0.1$

this motionese on infants' learning and memory of actions, as well as the effect of parents' prior evaluations of their infants' motor abilities on motionese. Parents' movements were motion-tracked while they demonstrated the unique action-effect pairs of four objects to their 14-month-old infants and two adult partners.

#### 4.1 | Parent kinematics

All quantified kinematics of parents' movements differed between IDAs and ADAs, suggesting that modulating 3D distance covered, velocity, proximity and effect duration are all characteristic of motionese. Parents also repeated action demonstrations more often for their infants than for adult partners. While proximity, effect duration and repetitions differed between IDAs and ADAs across all objects, 3D distance covered and velocity comparisons revealed action-specific modulations.

##### 4.1.1 | Action-specific modulations

###### 3D distance covered

The grey-shake object demonstrations were larger for infants than adults and for this object the act of moving it through the air is necessary for the rattle sound to occur. This effect was not found for the

other auditory-effect object, though, which likely reflects the physical constraints of twisting the orange object. Nor was there a significant difference in how far apart the yellow object's halves were pulled, which could be because parents focused on showing the two separated halves (i.e. effect duration modulations). At first glance, this action-specificity stands in contrast to general exaggerations found in rater-coded analyses (e.g. Brand et al., 2002; Rutherford & Przednowek, 2012). Yet while those studies consider the entire interactions, the analyses here regard only the actions. Instead, had we also quantified peripheral movements, such as handing the objects to partners, enhancements might have been found across objects. In line with this, parents made a larger approach movement towards the red-press object for IDAs than ADAs, reminiscent of the larger and curved motion paths parents made while stacking cups in the study by Rohlfing and colleagues (2006). These approach exaggerations similarly resemble the highlighting movements parents make while verbally labelling objects (Matatyaho-Bullaro, Gogate, Mason, Cadavid, & Abdel-Mottaleb, 2014; Yoshida & Burling, 2012). Thus, it is possible that movement size is exaggerated when permitted by the action (e.g. grey-shake vs. orange-twist objects) and in peripheral movements or on route to action-effects and end-states possibly to direct attention.



## Velocity

The two objects that caused auditory action-effects (i.e. grey-shake and orange-twist) were demonstrated more slowly in IDAs than in ADAs. Moving more slowly might make the action easier for infants to track visually, which is important when a specific movement is required for the sound effects as is the case for these two objects. Hence, the disparate findings of previous research (Brand et al., 2002; Rutherford & Przednowek, 2012) might have been caused by rating velocity across different types of actions. Furthermore, the action-effect specificity found here corresponds with Rohlfsing's and colleagues' (2006) cup-stacking study, which did not find evidence for a difference between infant- and adult-directed velocities. In that case, precisely how to move the cups is of less importance than where to move the cups and in which order. Similarly, in the present study, no evidence for differences between demonstration partners was found for the yellow-pull object, for which, the effect of having two separated halves is arguably more important than how to separate the halves. Moreover, this study's parents moved their finger towards pressing the red-press light faster during infant- than knowledgeable adult-demonstrations. Again, the precise movement of going to press is not important, while the act of pressing down to display the light is (i.e. effect duration). Possibly, faster and larger movements on route to pressing the light might serve an attention-grabbing function to ensure that the infant sees the visual action-effect.

Together, the 3D distance covered and velocity findings imply that when modulations occur and in which direction (i.e. increasing or decreasing) is dependent on the features and affordances of the action and effect of interest. These promising, though exploratory, findings open the door for further confirmatory investigations of parents' action-specific modulations and the learning mechanisms these might target.

### 4.1.2 | General modulations

#### Proximity

Across objects, parents performed actions closer to their infants than to adult partners. This finding replicates those of past studies in which this effect was found even when controlling for the difference in demonstrator-recipient relationships between infant- and adult partners by having parents demonstrate actions to friends or family members instead of strangers (Brand et al., 2002; Rutherford & Przednowek, 2012). This suggests that proximity might serve learning functions and hence not only be a social-engagement modulation (cf. Rutherford & Przednowek, 2012). The possible learning function of proximity is explored below.

#### Effect duration and repetitions

Parents also demonstrated all action-effects longer to their infants than to the adults. This corresponds with the cup-stacking study in which the pace, the ratio of action durations to pause durations, was lower for IDAs than ADAs (Rohlfsing et al., 2006). In cup stacking, pausing at the placement of a cup essentially demonstrates the effect of moving the cup, much like the effect duration measure used here. Furthermore, these results clarify disparate findings from

the past rater-coded studies, in which one study found mothers tended to spend longer in total demonstrating to adults than to infants (Brand et al., 2002) while the other study found no evidence for differences (Rutherford & Przednowek, 2012). Perhaps in these studies, longer effect demonstrations were lost in totalling over the entire demonstration durations. Authors of both studies further emphasized that infants spent more time with the objects than adult recipients and acted jointly on the object together with their parent for longer than the adults (Brand et al., 2002; Rutherford & Przednowek, 2012). While possession was not quantified in the present study, the higher number of repetitions for infants are likely reflective of more exchanges (as in Brand et al., 2007), and hence, longer infant- and joint-actions in total.

### 4.1.3 | Infant versus naïve adult

The significant differences between infant- and naïve adult-directed demonstrations suggest motionese modulations are not purely a function of recipients' object knowledge but instead at least partly infant-specific. The present findings resemble those of a recipient design study, in which adults made more adjustments when they thought they were communicating a hidden location to a child than another adult, even when the supposed-recipients were matched on performance (Newman-Norlund et al., 2009), indicating that additional (assumed) characteristics of young learners influence communicative actions. At the same time, though, there was no evidence for differences between naïve and knowledgeable adult demonstrations. Likely, parents did not perceive the naïve and knowledgeable adults to differ greatly. Parents could reasonably expect both adults to be capable of performing the actions, which was not necessarily the case for their infants. Also, neither the actions nor the effects were novel to the adults, only the specific action-effect pairs needed to be conveyed. Still, for the red-press object, 3D distance covered, velocity and effect duration did not differ significantly between the infant and naïve adult. Though this says little in itself, it provides the slightest suggestion for future research to investigate this more systematically. If actions are truly novel, such as complicated series of sports movements, naïve versus knowledgeable adult demonstrations might show modulations similar to motionese.

### 4.2 | Learning, memory and motor evaluations

Whereas this study's primary aim was to quantify IDAs, the empirical interest in motionese stems from its potential to facilitate learning. The explorative learning, memory and prior motor abilities evaluation analyses in this study, though limited in scope, support the notion that motionese might be beneficial to learning by drawing attention and highlighting the functions of specific actions. We speculate that parents showed a 'just right' modulation of proximity. Both parents' demonstrations preceding infants' successes and the demonstrations of parents considering their infant's motor abilities to be average were performed further from the infants

than the demonstrations preceding failed attempts or of the high-motor evaluation group respectively. So, even though IDAs were performed significantly closer to partners than ADAs, thinking an infant needs more assistance and, importantly, infants' actual learning were related to performing actions further away from them. This counterintuitive finding might be explained by the modulations that further proximity affords in other kinematic measures, such as 3D distance covered. Descriptively, although not significant, the learning and memory graphs show larger actions for successful than failed attempts, particularly for the grey-shake object. Similarly, at a level of marginal significance, parents who rated their infants as being average with respect to motor ability, and thus in more need of assistance, performed larger actions than the high-motor ability raters. Though 3D distance covered learning effects are possibly lost in the noisy data, the significant, negative correlation between 3D distance covered and proximity for the grey-shake object adds merit to this explanation. The further away the parents demonstrated the actions, the bigger their actions were. It thus seems that performing actions neither too far nor too close maintains infants' attention while allowing for modulations that emphasize action functions (e.g. making movements bigger) to be visible. In addition, not holding the object too close to the infant likely also means that they cannot manually interfere with the demonstration. In line with studies demonstrating the importance of the visual saliency and proximity of objects for name learning (Matatyaho-Bullaro et al., 2014; Yu & Smith, 2012), the present findings suggest that visual saliency during action learning includes being able to see the full action modulations. Nevertheless, experimental research is needed to investigate such a 'just right' modulation and its possible learning benefits.

### 4.3 | General discussion

Overall, the learning and memory investigations were explorative because collecting learning data in this design suffered from the noisy nature of natural interactions. Two essential aspects of natural interactions limit the findings of this study: their multi-directionality and multi-modality.

In this study, learning effects were quantified as a function of parents' prior kinematics to investigate how kinematics affect learning. Parents had not received instructions on how many times to exchange the objects, so this naturally varied between objects and dyads. This is evident from the significantly higher repetition counts of the orange-twist and red-press objects than the grey-shake and yellow-pull objects. The learning ratios and memory scores indicate that these same objects were the more difficult and easier objects respectively. This suggests that parents were sensitive to their infants' inabilities to perform the harder actions, hence repeating them more often. Yet, by measuring preceding kinematics, we only captured one direction of object exchanges. By making use of repetitive cup stacking, providing a multitude of data points, Fukuyama and colleagues (2015) measured how parents adjusted their movements after infants' attempted the action. Motion-tracked parents decreased the variance in their

motion paths across cups after their 11- to 13-month-old infant had performed the target cup-stacking behaviour but increased the variance if the infant had performed irrelevant actions with the cups (Fukuyama et al., 2015; for robot-directed actions: Vollmer et al., 2014). These previous and the present findings, including the influence of parents' prior motor ability evaluations, collectively indicate the importance of modulations occurring before and throughout a motionese interaction. In order to fully capture how motionese facilitates learning, future research needs to take this multi-directionality into account.

The present study focused on quantifying parents' kinematic adjustments, yet these analyses neglected at least three additional modalities of information exchange, which the parents had been free to employ naturally. First, in the original motionese study, parents' heightened interactiveness and enthusiasm were hypothesized to enhance infant attention and facilitate learning (Brand et al., 2002). Since then, saliency-based computational analyses have identified parents' social-emotional signals as action-boundary markers during IDAs (Nagai & Rohlfing, 2009) and several studies have found that social-emotional cues facilitate infants' imitation (Fukuyama & Myowa-Yamakoshi, 2013; Shneidman, Todd, & Woodward, 2014). Second, IDAs have also been found to consist of more and longer parental eye gaze bouts than ADAs (Brand et al., 2007) and later work revealed that mothers aligned their infant-directed gazes with action boundaries and with actions completing enabling sequences (Brand, Hollenbeck, & Kominsky, 2013). Third, IDS has received considerable attention as a parental modulation that facilitates infants' learning (Eaves, Feldman, Griffiths, & Shafto, 2016). Far from being an isolated modality only relevant for language learning, though, emerging evidence suggests that linguistic modulations, like enhanced social-emotional and eye gaze cues, co-occur with motion modulations (Nagai & Rohlfing, 2009; Rohlfing et al., 2006; ) and together optimize action learning conditions (Brand & Tapscott, 2007; ). Complementarily, extensive evidence exists for the opposite effect, namely that motions of parents and infants can facilitate language learning (Chang, de Barbaro, & Deák, 2016; Gogate, Bolzani, & Betancourt, 2006; Gogate & Maganti, 2017; Gogate, Maganti, & Laing, 2013; Matatyaho & Gogate, 2008; Matatyaho-Bullaro et al., 2014; Nomikou, Koke, & Rohlfing, 2017; Rader & Zukow-Goldring, 2012; Yoshida & Burling, 2012). Consequently, for the teaching potential of parental modulations to be fully understood, future research must consider the entire repertoire of infant-directed behaviours.

In conclusion, this motion tracking study revealed that parents modulate IDAs generally, by performing actions closer to infants and by demonstrating effects for longer, and specifically, by performing larger movements when afforded by the action and moving more slowly when the movement is essential for the action-effect. Infants seemed to have learned better when parents struck a balance between performing actions close by but with room for kinematic modulations. These context- and action-based variations in modulations and learning effects suggest that motionese is geared towards grabbing infants' attention and highlighting



action functions. Hence, while parents are busy making their actions appealing for their infant learners, we have our work cut out for us to further understand the learning potentials of this intricate set of modulations.

## CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflict of interest.

## ACKNOWLEDGEMENTS

The authors extend their gratitude to Natalie Sebanz, Cordula Vesper and Laura Schmitz for sharing their insights at the initiation of this project. The authors thank Gerard van Oijen, Norbert Hermesdorf and Mark van de Hei for producing the objects and Erik van den Berge for his extensive assistance in setting up the motion tracking. The authors also thank Angela Khadar and Hilde Krajenbrink for assistance in recruitment and coding. Also the authors extend their gratitude to all families for their valuable participation!

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author (Johanna van Schaik) upon reasonable request.

## ENDNOTE

<sup>1</sup> Due to repeated failure of the effect of a fifth object (a blue object which should “moo” when turned upside-down), this object was excluded from the analyses.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**How to cite this article:** van Schaik JE, Meyer M, van Ham CR, Hunnius S. Motion tracking of parents' infant- versus adult-directed actions reveals general and action-specific modulations. *Dev Sci*. 2020;23:e12869. <https://doi.org/10.1111/desc.12869>