WILEY | INFANCY THE OFFICIAL JOURNAL OF THE INTERNATIONAL CONGRESS OF INFANT STUDIES

RESEARCH ARTICLE OPEN ACCESS

Exploring 12-Month-Old Infants' Processing of Other People's Manual Actions: A Motor Interference Paradigm

Áine Ní Choisdealbha[1,2] | Andrew N. Meltzoff[1,3]

[1]Institute for Learning & Brain Sciences, University of Washington, Seattle, Washington, USA | [2]School of Psychology, University College Dublin, Dublin, Ireland | [3]Department of Psychology, University of Washington, Seattle, Washington, USA

Correspondence: Áine Ní Choisdealbha (aine.nichoisdealbha@ucd.ie)

Received: 5 August 2025 | **Revised:** 10 January 2026 | **Accepted:** 21 January 2026

Handling Editor: Tilbe Goksun

Keywords: action perception | action production | grasping | motor development | social cognition

ABSTRACT

Inferring the goals of other people's actions is an important aspect of early social cognitive development. Using an experimental manipulation, we investigated the role of infant motor processes in the processing of action they see performed by another person. We designed a procedure in which we inhibited infants' concurrent access to motor representations of precision grasping as they observed the reach-to-grasp action of an adult experimenter. In a within-subjects design, 48 12-month-olds watched adult reach-to-grasp actions under two conditions of hand posture in randomly-assigned order: (a) hands free and (b) hands constrained in a manner that blocked their grip formation. Infant looking times were measured as an experimenter reached toward large and small objects, using a power or precision grip type. Infants' prior-existing fine motor skills were assessed using a standardized parental report questionnaire. Results showed that infant looking times varied as a function of the interaction between infants' existing fine motor skill and their experimentally-manipulated access to motor representations of the action ($p = 0.017$). The better an infant's fine motor skills, the greater the reduction in their looking to the object congruent with the actor's grip type under the motor interference induced by hand constraint. This effect was particularly pronounced during the precision grip trials ($p = 0.032$). These findings advance our understanding of the role that infants' self-experience plays in the processing of the manual actions of others. More generally, such results inform theories about the functional significance of action perception-production links in early human development.

1 | Introduction

During the first year, infants can predict the goals or endpoints of other people's actions. They anticipate that adults will bring functional objects like cups and hairbrushes to the relevant target (mouth or hair; Hunnius and Bekkering 2010), and they look longer at a scene when an adult switches the target of their reach from a previously-established one (Woodward 1998). Such action processing is theorized to be a precursor to later social-cognitive development, because it provides infants with patterns of behavioral data with which to enrich their understanding of the desires, goals, and intentions of other people (e.g., Meltzoff 2007, 2013; Schwarzer and Jovanovic 2024).

There is a rich and varied empirical literature on how motor processes and action experience may influence infants' perception and interpretation of others' actions (e.g., Chung et al. 2022; Gerson et al. 2015; Marshall and Meltzoff 2014; van Elk et al. 2008). Here, we focus on reaching and grasping as fundamental, early-developing actions. Researchers have exploited the development of different types of grips to explore interactions between motor representations and action perception. In adults and school-age children, experimental interventions have been designed to inhibit participants' access to motor representations, by placing the hands in an unusual posture as participants solve various perceptual-cognitive tasks that may draw on motor imagery (e.g., Ambrosini et al. 2012; Sekiyama et al. 2014). In this paper, we adapt this type of intervention approach for research with infants.

1.1 | Motor Processes in Infant Action Perception

A substantial empirical literature has described how infants learn to predict and encode other people's actions. By 6 months of age, infants predict the outcomes of familiar adult actions (e.g., Hunnius and Bekkering 2010; Woodward 1998). There are multiple theoretical accounts about how such action processing develops, and these perspectives are not mutually exclusive (Ní Choisdealbha and Reid 2014). One prominent view is that infants' experience of performing actions affects their action perception (for reviews, including critical perspectives, see Bertenthal and Boyer 2025; Hunnius and Bekkering 2014; Ní Choisdealbha and Meltzoff 2025). There is also evidence that infants encode the outcomes of actions that they cannot (or cannot yet) perform (de Klerk et al. 2016; Southgate et al. 2008), which suggests that there must be action perception processes that are not fully dependent on the infant's own experience. Nonetheless, many studies have demonstrated an effect of acquiring motor skills or experience on infants' action perception (e.g., Cannon et al. 2012; Sommerville et al. 2005; Stapel et al. 2016)—in other words, some form of perception-production link.

There are multiple mechanisms through which motor experience could affect perception. These are summarized by Schwarzer and Jovanovic (2024) as: (a) improving statistical inference; (b) generating new conceptual knowledge; as well as (c) providing internal motor models of actions. Historically, it has been challenging to disentangle the effects of visual versus motor components of active experience on action perception. On the one hand, it may be that production experience provides infants with an internal motor representation that they can use to process the observed action and infer the end-state. On the other hand, it may be that as infants gain production experience, they have more self-generated occasions to see that action, thus improving their statistical or conceptual representation of that action independent of the motor components of the experience. These alternatives are neither mutually exclusive nor exhaustive, and both could be at work simultaneously (e.g., Meltzoff and Brooks 2008; Skerry et al. 2013).

For example, in the "sticky mittens" paradigm, 3-month-old infants are given experience picking up objects through the use of special mittens which adhere to the objects they reach out and touch. Infants given sticky mittens training look longer when an actor changes the target of their reach, while those without such experience do not (Sommerville et al. 2005). The outcome of training, however, may not be due to the motor experience in and of itself, but to the additional conceptual, statistical, or physical-causal information obtained through active experience (Liu and Almeida 2023; Woo et al. 2024). Consequently, disentangling the effects of motor models of action from other visual, statistical, or conceptual models could help to clarify the specific role of motor processes per se in action perception.

1.2 | Motor-Related Brain Activity and Action Perception

One approach that has been taken in infant neuroscience studies is to record the desynchronization of the motor-related EEG mu rhythm in infants while watching goal-directed actions (Marshall and Meltzoff 2014; Nyström 2008; Nyström et al. 2011; Southgate et al. 2009, 2010). There is evidence that mu desynchronization is linked to infants' own experience with action production. Studies have shown greater mu desynchronization in 9- to 14-month-old infants to familiar than to novel actions, with the strength of the response modulated by various experiential factors including motor training (Gerson et al. 2015), competence at performing the relevant motor behavior (Chung et al. 2022), and months of experience after a relevant motor milestone was first reached (van Elk et al. 2008).

Similar to the behavioral evidence, the link between mu desynchronization and action experience in infants does not negate that multiple processes—motor, statistical, and conceptual—may be at play. For example, observational-only learning of statistical action probabilities leads to more mu desynchronization in 18-month-olds during prediction of an upcoming action (Monroy et al. 2019), and infants show mu desynchronization in response to actions they cannot (or cannot yet) perform (de Klerk et al. 2016; Southgate and Begus 2013). These, and other findings raise interesting questions about the precise motor representations or models elicited when mu desynchronization is documented in infants (de Klerk et al. 2015; Marshall et al. 2011; Saby et al. 2013).

While acknowledging that there are multiple possible and complementary routes to the development of action perception and related neural processes, there are many findings suggesting that infants' neural motor representations may be influenced by experience (e.g., Chung et al. 2022; Gerson et al. 2015; van Elk et al. 2008). However, these studies do not necessarily show that motor experience directly alters how infants interpret or process the action in a manner separable from the visual, statistical, or conceptual experience that is also obtained via the motor performance. To more directly examine the role of motor processes in action perception, we consider behavioral research paradigms which have exploited infant looking behavior to draw inferences about infants' perceptual anticipations about others' actions.

1.3 | Production and Perception of Different Types of Grip

Reaching to grasp is a goal-directed action which has formed the backbone of infant action perception research. Infants' own experience of reaching and grasping has been linked to action perception using multiple measures, including looking times (Sommerville and Woodward 2005), predictive looking (Cannon et al. 2012; Melzer et al. 2012), and event-related potentials (Ní Choisdealbha et al. 2025). While the emphasis has often been on the goal of the action, variations in grasping illustrate how infants encode the form and dynamics of action performance, including hand orientation (Bakker et al. 2015; Bakker et al. 2016) and grasping errors (Meyer et al. 2016).

Precision and power grips can both be used to achieve the goal of grasping, but differ from each other visually, motorically, and in terms of which objects afford each grip type. Infants learn to use power grips first. The emergence of the precision grip is a particularly important transition in motor development. Although infants begin to use the thumb in grasping from four or 5 months of age (Halverson 1931; Newell et al. 1989), thumb-to-forefinger (i.e., precision) grasping does not become readily available to infants over whole-hand (i.e., power) grasping until eight to 9 months of age (Butterworth et al. 1997; Halverson 1931). Crucially, there is considerable inter-individual variability in the development of the precision grip. For example in Touwen's (1971) study of 27 infants, the precision grip emerged between 6 and 10 months. Butterworth et al. (1997) reported that the most sophisticated form of precision grasping, the pincer grip, was demonstrated by few 6- to 8-month-olds, about half of 12- to 14-month-olds, and all of the 15- to 20-month-olds in their sample.

Thus, across the latter half of the first year, most infants acquire experience of grasping with both power and precision grips, albeit at different developmental times. Infants also learn to distinguish between these grips as used by others. Daum et al. (2009) found that at six and 9 months, infants looked longer at a pictured grasping outcome that was incongruent with the actor's hand posture during reaching. For example, if the original reaching posture was a wide hand shape, infants looked longer at a pictured end-state in which the hand grasped the narrow handle of the cup than one in which it grasped the wide, round body of the cup.

The general goal of "grasping" can be achieved by both power and precision grips, but it is possible that self-experience (motor, visuomotor) with both precision and power grasping (and their different affordances) would help infants to distinguish between them in the context of action perception. Across multiple methodologies, relations have been found between precision grasping ability and perception of such actions. Employing a preferential looking paradigm, Daum et al. (2011) found that 6-month-olds who used thumb opposition looked longer at an incongruent grasping action outcome, while those who used only palmar grips did not. Using predictive looking, Ambrosini et al. (2013) found that infants from 8 months of age anticipated the target of a reaching action with a precision grip, and anticipation was related to the infants' own grasping ability. Filippi and Woodward (2016) found that 13-month-olds' ability to pre-shape their own hands to successfully grasp an object was significantly related to how quickly they anticipated the goal of an actor's reach based on the hand shape. In a habituation paradigm, Loucks and Sommerville (2012) found that 10-month-olds who could successfully use a precision grip to retrieve an item from a narrow tube responded differently to changes in grasping actions than infants who could not perform functional precision grasping. Specifically, while both groups dishabituated when the actor's grip shape changed, only the precision graspers dishabituated when the grip became non-functional.

1.4 | Adult Studies of Motor Imagery and Motor Interference

The foregoing findings invite us to dig deeper into the question of *how* action experience affects infants' action perception. Although neural motor activation occurs during action observation, it is not clear whether this activation plays a role in helping infants process the observed event. We reasoned that one experimental approach that may be useful in making this distinction in infants is to examine what happens when motor representations are blocked or inhibited.

In adults, brain stimulation methods like transcranial magnetic stimulation (TMS) have been used to investigate the effects of targeted stimulation over premotor areas (Avenanti et al. 2013). Targeted magnetic stimulation to the premotor (inferior frontal cortex) region disrupts recognition of power and precision grips, and processing of new action goals (Jacquet and Avenanti 2015). However, restrictions in the use of TMS in research with infants mean that alternative interference methods must be found. A non-invasive behavioral paradigm used with adults found that anticipatory looking toward the target of a simple action (placing balls in a bucket) was disrupted by an active motor task (tapping the fingers) but not by a working memory task (Cannon and Woodward 2008). The authors interpreted this as suggesting that interference with the motor system, via performance of an unrelated motor task, disrupts action perception.

In adults, it has also been found that directly manipulating hand posture influences performance in tasks requiring motor imagery of the hand. For example, in the hand laterality task (HLT), people typically determine whether a visually-presented hand is a left or right hand by mentally rotating a motor representation of their own hand into the same position. Response times increase when the person's performs this perceptual judgment task when their own hand is placed in an unusual spatial position (Ionta et al. 2007; Ionta and Blanke 2009; Ní Choisdealbha et al. 2011). Relatedly, it has been shown that even a simple posture manipulation (flexing the arms across the body) modulates the activation of HLT-involved brain areas (specifically the intraparietal sulcus [IPS]; de Lange et al. 2006).

In adults, the effects of posture manipulation are also manifest in action perception tasks, including perception of grasping actions. Using eye-tracking, it was found that binding adult participants' hands, so they cannot perform grasping actions, results in later visual time-of-arrival at the target of a grasping action (Ambrosini et al. 2012). It also results in slower reaction times when asked to predict when an experimenter's hand will grasp an object (Craighero and Zorzi 2012). In a more intensive motor interference approach, Toussaint et al. (2023) immobilized participants' dominant arm for 24 h, and found that this reduced accuracy at determining how to grasp tools for specific actions (Toussaint et al. 2023). On a neural level, the congruence between an adult's hand posture and the end state of planned or observed grasping actions affects IPS activity (Zimmermann et al. 2012, 2013). The results of these adult motor interference paradigms have been used to support the idea that adults use motor processing in perception of manual actions.

1.5 | Developmental Studies Using Posture Manipulation

Developmental work suggests that motor constraints also affect children's performance in visual perception tasks likely to engage motor processes. Sekiyama et al. (2014) did not manipulate posture directly, but had grade school children engaged in a hand laterality task hold a controller to prevent them from solving the task using overt movement. In line with adult work, they found that the more biomechanically difficult it would be to rotate one's hand to match the displayed stimulus, the longer children's response times. They also found that this effect was strongest for the younger age groups, suggesting that younger children were more reliant on motor processes in this task, and less likely to switch to a different, non-motor strategy with increasing task difficulty.

The findings of Sekiyama et al. (2014) suggest that children engage motor processes in visuomotor tasks, but does not tell us whether infants use motor processes in action perception tasks. In infants, manipulations of posture or hand position have been used in other contexts, specifically to study developmental changes in multisensory integration (Begum Ali et al. 2015; Bremner et al. 2008; Rigato et al. 2014). This work indicates that experimental manipulations of posture in infants are at least feasible. We reasoned that a new infant posture intervention that specifically interfered with infants' ability to form a thumb-opposite grip, while infants observed an adult performing a reaching action using that grip, could advance our understanding of the processes involved in infants' perception of other people's actions. This motor interference approach contrasts with active skill training (e.g., sticky mittens) and could help dissociate motor and non-motor mechanisms underlying the effects of training interventions.

1.6 | Rationale of Current Study

The aim of the current study was to examine whether experimentally-imposed motor interference would alter infants' perceptual processing of an action they observed another person perform. We used a within-subjects, experimental approach. Two postural conditions were used: one in which the infants' hands were free and another in which the fingers were constrained in a posture that prevented production of a thumb-opposite grip. We examined infants' looking times to the locations of two objects during an event in which an adult experimenter reached with a hand pre-shaped in a power or precision grip toward these two objects, from which the hand was equidistant. One object was congruent with the power grip and incongruent with the precision grip, and vice versa for the other object.

We recruited 12-month-olds because by this age, virtually all typically developing infants should have experience in performing and functionally using precision grasps (Butterworth et al. 1997; Halverson 1931; Touwen 1971). Nonetheless, we believed that variations in infants' "priors" before participating in the experiment—their level of motor skill—would play a role in their encoding of the action during the study. To explore individual variations in motor skills, we collected motor development data via a parent-report instrument, the Early Motor Questionnaire (Libertus and Landa 2013; Smith and Libertus 2022).

2 | Methods

2.1 | Participants

Participants in the analytic sample were 48 infants (24 male, 24 female) at 12 months of age (M = 52.29 weeks of age, SD = 0.94, range = 50.86–54.00 weeks). An additional four infants (three female, one male) began the study but refused to wear the postural manipulation tape or mittens and therefore were excluded. The study took place in Seattle, Washington, USA. In the analytic sample 75% of the infants were White, 4.17% were Asian, and 18.75% had Multiracial backgrounds. For 93.75% of the sample, at least one parent had a Bachelor's degree or a postgraduate qualification. One parent did not provide demographic information. The 48 infants in the analytic sample each had a minimum of 11 valid trials out of a total possible of 16 (M = 15.31 trials, SD = 1.09, range = 11–16; see below for more details on trial exclusions and validity). Ethical approval for the study was granted by the University of Washington Institutional Review Board.

Prior to the study, a novel test apparatus and procedures was devised through a planned pilot study, which included 15 infants and provided data for power analyses. Because we planned to use multilevel mixed effects models, and because conducting a power analysis for such a model would require complex simulation, we extrapolated the pilot effect sizes to a repeated-measures analysis of variance (ANOVA) in G*Power (Faul et al. 2007), which suggested an N of 38 infants, using a projected effect size of 0.36 for the effect of object congruence on looking time (alpha error probability = 0.05, power = 0.95). We over-recruited with a fixed stopping rule of 48 infants (24 male, 24 female) after exclusions for incomplete testing sessions.

2.2 | Materials

2.2.1 | Reaching Apparatus and Test Objects

We constructed a special apparatus, a "reaching chute" that could be used to show infants a live adult reaching toward target objects in a repeatable, controlled manner (see Figure 1). This apparatus consisted of a Y-shaped chute constructed from matte black plastic (0.5 cm thick). The main channel (the stem of the "Y") was 22.5 cm wide and 30 cm in length; each of the wings of the "Y" was 30 cm long. The angle of the wings was 135°. This

A. B.

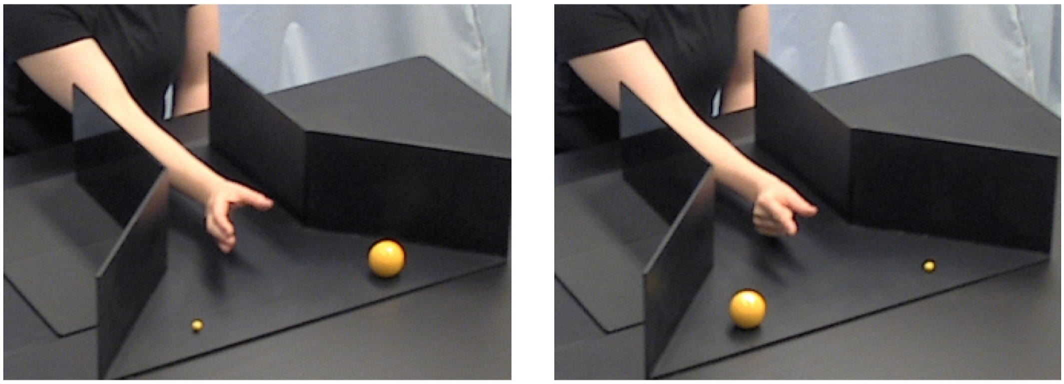

FIGURE 1 | The Y-shaped reaching chute showing the objects and experimenter's reaching actions. The photographs illustrate the two adult grip types as the experimenter's hand moves down the reaching chute at midline, equidistant from both objects. (A) The live experimenter displays a power grip that is "congruent" with the large sphere. (B) The live experimenter displays a precision grip that is "congruent" with the small sphere.

Y-shaped set-up allowed the experimenter to reliably repeat a controlled manual pickup event in 3-dimensional space.

The objects presented to the infant during the test trials were pairs of yellow and red spheres and cubes. The sphere pair consisted of small (1 cm diameter) and large (4 cm) spheres; and the cube pair consisted of small (1 cm^3) and large (4 cm^3) cubes. Each object was placed on a small mark on the apparatus (Figure 1). There was 30 cm distance between the marks; the objects were situated 70 cm from the edge of the table where the infant was sitting, leading to a difference in viewing angle between the objects of 25° for the infant.

2.2.2 | Video Recording Equipment

Infants' looking and grasping behaviors were recorded with three digital cameras. The cameras recorded at a rate of 30 frames/s, and were synced by a time-generator which inserted a time record at a frame-by-frame level. Camera-1 was a high-definition camera focused on a closeup of the infant's face, torso and arms and recorded the infant's behavior. Camera-2 was a high-definition camera situated behind the infant that captured a view of the table, the apparatus, the experimenter's torso, face, and arms, and a portion of the back of the infant's head. Camera-3 was a standard-definition camera that provided an over-head view showing the infant and their parent's torso from above. A microphone mounted alongside Camera-3 recorded sound. No portion of the experimenter's behavior or the test objects was visible in the Camera-1 or Camera-3 views, enabling blind coding of the infant behavior.

2.2.3 | Infant Hand Posture Manipulation Materials

The experiment required test conditions in which the infant's hands were fixed in a posture that prevented or interfered with emulation, overt or otherwise, of a grasping action as they watched the adult's reach and grasp. This was achieved by gently taping the infants' fingers into a particular posture (described below). The tape used in this manipulation was one-inch wide 3M Nexcare sensitive skin tape, which is often used to affix sensors to adults, children, and infants in neurophysiological experiments. The infant's taped hand was then covered with a commercially produced thumbless mitten. Infants engaged in social interaction and play with the experimenter before and after the placement of the tape and mittens.

Tolerance for the procedures was probably facilitated at this age by the familiarity of mitten-wearing (e.g., for warmth, to prevent face-scratching), and previous experience with adults restricting infants' hands (e.g., clasping of hands and fingers by parents to prevent reaching for risky objects). Just as infants tolerate wearing other physical items during experiments (e.g., EEG caps, head cameras), the hand restriction method we developed was accepted by most of the 12-month-olds after a short period of acclimation, and did not seem to affect engagement with the adults and objects in their environment (see "Results" section).

2.2.4 | Standardized Parental Questionnaire on Infant Motor Behavior

Parents completed the Early Motor Questionnaire or EMQ (Libertus and Landa 2013). We provided parents with the questions suggested for infants of 12 to 13 months (Smith and Libertus 2022) from the three EMQ subscales: (a) fine motor skills (items 21–48), (b) gross motor skills (items 23–49), and (c) perception-action (items 12–31). For the EMQ, skills and behaviors are listed, and parents select an integer score between −2 and +2 for each skill, corresponding to how certain they are that the child does not or does show that specific behavior. The scores for each subscale—fine motor, gross motor, perception-action—were obtained from the sum of all numerical scores (−2 to +2) for each item in each subscale. Missed questions were scored as 0. Resulting values were then converted to z scores for each individual sub-scale, using the mean and standard deviation values for this sample. The fine motor subscale was most relevant to the empirical task used in the current study.

2.3 | Design

This study employed a 2 (infant hand posture) × 2 (adult grip type) within-subjects design. More specifically, the first factor was the experimental infant "hand posture" manipulation, which had two levels: hands free or hand constrained. The infant's hands were free in one half of the experiment and constrained by tape in the other (counterbalanced order across infants). The other experimental factor was the grip type displayed by the adult experimenter as she reached for the objects, hereafter labeled as "adult grip type." This had two levels: adult power grip display versus adult precision grip display. Each infant was presented with an equal number of trials in which the adult grip type was in the precision versus power grip (within each half of the experiment). The experimental design had two blocks of eight trials, one block with the infant's hands free and the other with the infant's hands constrained (fingers taped). Within each block of eight trials, four trials involved one pair of objects (e.g., a large and small yellow sphere, see Figure 1), and the other four involved a second pair of objects (e.g., a large and small red cube). For more details on counterbalancing, see Supporting Information S1, Section 1.

On each trial the experimenter moved her hand down the reaching chute (at midline, equidistant from the two objects), displaying one adult grip type. On "power grip" trials, her thumb and four fingers were wide apart, as if reaching for a large object like a tennis ball (Figure 1A). On "precision grip" trials her hand was held with the thumb and index finger close together, as if reaching for a narrow object like a pen or cup handle, and the remaining fingers flexed against the palm (Figure 1B). For trials in which the experimenter was displaying a power grip, the large object was termed "the target object," and labeled as being "congruent" with the hand grip (the small object was labeled as "incongruent"). For trials in which the experimenter was displaying a precision grip, the small object was termed "the target object," and labeled as being "congruent" with the hand grip (the large object was labeled as "incongruent"). The experimental question was whether the infant would preferentially choose to look at the congruent object as the experimenter's hand came down the chute (at midline, equidistant from both objects), prior to the experimenter committing to reach to the left or right object.

2.4 | Procedure

Experience of working with this age group during piloting had indicated that most 12-month-olds required a warm-up period to become used to seeing the apparatus and observing how the experimenter used it, as is common in experiments with live adults (e.g., Barragan et al. 2020). The structured warmup took about 2 minutes and took place before the blocks of trials in which the infants' hands were free, and before those in which their hands were constrained. A detailed description of the infant warm-up period with the live stranger can be found in the Supporting Information S1, Section 2.

2.4.1 | Test Trials

At the start of each set of experimental trials, the experimenter selected the first pair of objects (spheres or cubes) in the sequence for that particular child and, keeping them out of view of the infant (behind the walls of the chute), drew the child's attention to herself by asking "What have I got?" or a similar question. She then raised the objects into view above the apparatus where the child could see and said "I've got yellow/red balls/cubes!" as appropriate. She leaned forward over the apparatus, placed the objects on the left and right marks on the platform and sat back down. This meant the infant was provided information that the experimenter had seen and engaged with both objects in their respective locations. She then engaged in a series of four test trials strictly following the order counterbalanced according to a previously-determined sequence (see Supporting Information S1, Section 1), before standing up, removing the pair of objects and placing them out of view behind the chute again, and repeating the process with the next object pair. The counterbalancing means that infants were exposed to equal numbers of each grip type during placements and during trials, and thus viewing the grips during placement was unlikely to differentially affect their looking behavior.

The beginning and end of each trial was clearly defined. Each trial began when the experimenter put her hand at the standard start position in which her hand was raised from below the table edge on her side of the apparatus, just behind the opening of the chute, and positioned centrally relative to the walls of the chute. During each reaching act the experimenter slowly moved her hand down the chute in a straight line while displaying a particular hand grip size and keeping her eyes on the center of the apparatus platform. The looking-time trial ended just before the experimenter's hand moved left or right toward the target object. By experimental design this occurred at a standardized location, when the experimenter's wrist came to the end of the chute (see Figure 1). Infant looking time was measured while the adult was moving in a straight line, prior to the moment that the adult moved her hand toward the left or right fork of the "Y." Any looks to the objects that occurred *before* the infant looked at the middle of the scene, where the experimenter was, were not counted because the infant would not have seen the experimenter's grip type. A trial was only valid if the infant looked at the middle of the scene before the end of the trial.

After the looking trial ended, the experimenter's hand moved laterally toward the congruent object. The object was picked up, raised about 10 cm, and replaced on the platform. The experimenter then retracted her hand and placed it back below the table before initiating the next reach down the chute. This process was performed four times per object pair (two pairs of objects per hand posture condition). At the end of this first block of eight trials, the child's hand posture was changed, from hands free to hands constrained or vice versa, and a second block of eight trials was performed.

2.4.2 | Infant Hand Constraint Procedure

Before the block in which the infant's hands were constrained (hereafter, the "hands constrained" block), the experimenter sat at the table at 90° from the parent and infant. As noted above, and in Supporting Information S1, Section 1, the hand constraint block was the first block of eight trials for half of the infants, and the second block for the other half. Using toys to distract the infant, the experimenter tore tape strips of approximately 10 cm. She then gently took one of the infant's hands and wrapped the tape over the thumb and first two fingers, ensuring that the thumb was fastened alongside the index and middle fingers (Figure 2A). She then put one of the mittens over the infant's hand and repeated this process with the infant's other hand (Figure 2B).

2.5 | Data Scoring and Processing

2.5.1 | Looking Time: Measures

The primary outcome measure was the infant's relative preference for looking at the congruent versus the incongruent object. To derive this measure, we first obtained the amount of time the infant spent looking at the congruent and incongruent objects respectively. In contrast to traditional two-alternative looking time paradigms (e.g., the video-presentation paradigms in Daum et al. 2009; Daum et al. 2011), our dynamic trials presented at least three areas of interest to the infant: (a) the live experimenter's reach-and-grasp movement and grip type, (b) the congruent object, and (c) the incongruent object. This means that there is a need to normalize preference between trials in which the infant looked at the experimenter for the majority of the trial, and those in which the infant looked at the experimenter only briefly, then fixated one of the objects.

In order to overcome this issue, we calculated looking times as a percentage of the amount of time the infant spent looking at the scene on each trial. Looking at the scene (hereafter, "engaged looking time") was defined as the time infants spent looking at the objects, the experimenter, and the Y-shaped reaching chute; and did not include time looking away from the scene (or time when the eyes were obscured from the camera). On average, trials were 3501 ms in duration (SD = 446 ms), and looking engagement at the scene was 3059 ms (SD = 846 ms) per trial. To calculate the relative preference score, we subtracted the time spent looking at the incongruent object from the time spent looking at the congruent object, and calculated this as a percentage of engaged looking time. Further information on the appropriateness of this approach to the dependent variable, relative to other approaches, is considered in the Supporting Information S1, Section 3.

A secondary measure was gaze arrival, which provides a measure of anticipatory looking behavior (e.g., Cannon et al. 2012; Falck-Ytter et al. 2006; Melzer et al. 2012). The time at which the infant first looked to the congruent object in a given trial was subtracted from the time at which the experimenter's hand touched the object, providing a gaze arrival value (expressed in milliseconds). Positive values indicate an "anticipatory look," and negative values a "reactive look." The gaze arrival analysis and results are reported in the Supporting Information S1, Section 4. The pattern of gaze arrival findings is substantially the same as the primary outcome measure. Gaze arrival or latency has been used in some dual-target looking paradigms (Ambrosini et al. 2013; Filippi and Woodward 2016), however pilot data had indicated that the extended length of trials in the current paradigm (3 s, vs. 1 s in other paradigms) permitted visual exploration via multiple gaze shifts before the target object was reached. Consequently, overall looking preference was chosen as a more appropriate measure.

2.5.2 | Looking Time: Scoring

ELAN was used to score the videos in multiple stages. Trained coders were instructed to mark onsets and offsets of the trials and of the experimenter's grasping-to-lift action on the object (henceforth, the object-lifting period). These coders also made note of any invalid trials, for example if the parent pointed to or

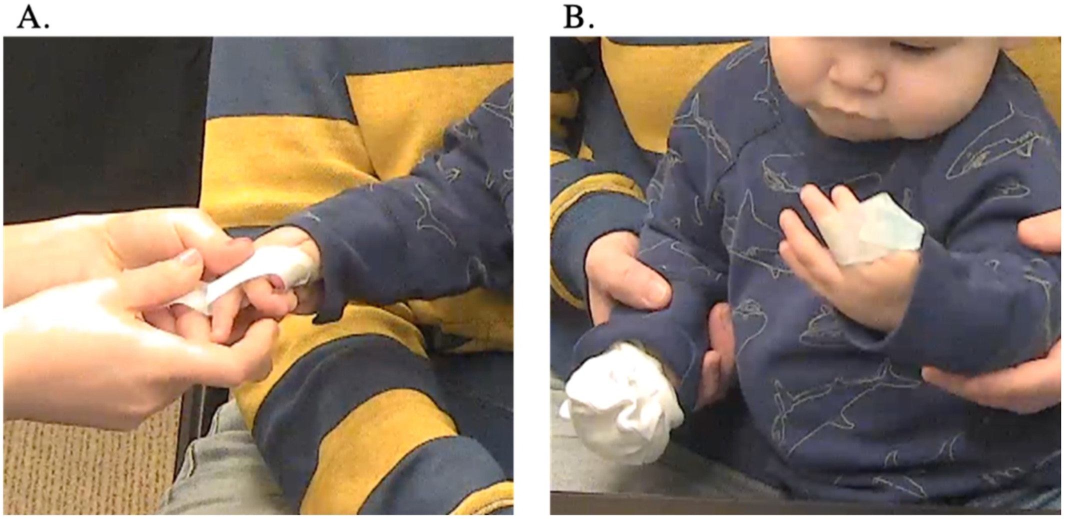

FIGURE 2 | The tape and mittens used for hand constraint. (A) Experimenter in the process of applying tape to an infant's hand. (B) One taped hand with the mitten covering it and the other hand taped in final preparation for covering the hand with the mitten.

named one of the objects, or if one of the objects rolled out of place during the trial. More detail on these scoring procedures is provided in Supporting Information S1, Section 3.

The ELAN files containing the trials and the Camera-1 (infant) and Camera-3 (overhead) videos showing the infant only were provided to a different trained looking-time coder who was blind to both: (a) the purpose of the study and (b) the parental EMQ responses. Because this coder did not have access to Camera-2 (showing the experimenter), they remained blind to the experimenter's grip type and to the location and features of the objects on the platform. This coder scored where the infant was looking frame by frame (scored as "right", "left" or "mid") on the basis of Camera-1 (infant) footage. The "mid" category referred to the area in between the objects, which encompassed the experimenter and the center of the chute, that is, looking engagement to the scene that was not specifically at the congruent and incongruent objects. As noted in the procedure section, a "mid" look was required before infants' looking behavior in the trial could be counted as valid. That is, infants needed to look to the area where the actor's hand grip shape was displayed before the infant's looking to the objects could be meaningfully counted as looking to a "congruent" or "incongruent" object. Camera-3 (overhead) was used if needed to confirm the position and rotation of the infant's head. The coder also scored frames as "obscure" when the infant's eyes were hidden (e.g., behind a hand) or out of frame, and "away" if the infant was not looking at the scene. Every frame from the onset of the trial to the offset of the object-lifting period was scored. Once this was done, the coder also made note of the first valid look (i.e., after the first "mid") to the right and to the left in each trial.

A second coder scored 24 videos (50% of the sample). Frame-by-frame agreement was 94.65% of frames, with a range of 88.69%–99.29% per infant. Overall Cohen's kappa was high, $\kappa = 0.91$, with a per-infant range of 0.84–0.98. After the first and second coders had completed their scoring, the coders who had inserted the onsets and offsets of the trial and the object-lifting period added another tier to the ELAN files to record the color, shape and location of the target object. They also recorded whether the experimenter's hand was shaped for power or precision grasping.

2.5.3 | Data Processing

Custom code was written in Python to convert the "left" and "right" looks recorded in the video-coding software to congruent (i.e., location of the look matched location of the target object) and incongruent categories. Invalid trials were removed, and the total amount of time each infant spent looking at the congruent and incongruent object in each trial (after their first look at the "mid" location) was calculated, as was the amount of time spent looking at the "mid" location. "Engaged looking time" per trial was computed as the total amount of time looking at "congruent," "incongruent," and "mid." For each valid trial, the difference in looking to the congruent versus incongruent object (numerator) was divided by the amount of engaged looking time (denominator) for each infant, and converted to a percentage. These percentages were then averaged per infant, per block (hands free or constrained) and per adult grip type (power or precision grip) to obtain each data point.

Potential data points were removed if the infant looked at neither the congruent nor the incongruent object during the trials. Thirteen values were removed because of these zero values (infant did not look at either congruent nor incongruent object), and one additional value was removed for being more than 3.5 standard deviations below the mean. The final processed sample contained 178 datapoints (of a potential 192), with 12 individual infants losing one datapoint each and one infant losing two datapoints. Dropped datapoints were spread across conditions.

2.6 | Analysis Plan

The data were analyzed in a linear mixed effects model (LMEM) using the lmerTest package in R (Kuznetsova et al. 2017). The fixed experimental factors were infant hand posture condition (hands free or constrained), adult grip type (power or precision), and the interaction between these factors. The factors were contrast-coded, with the hands free condition set to −0.5 and the hands constrained condition set to 0.5. For adult grip type, power grip was set to −0.5, and precision grip to 0.5. The infants' fine motor EMQ subscale z scores were also entered into the model, along with their two- and three-way interactions with the experimental factors. There was a random intercept on participant identity and a random slope on adult grip type. The results of an analysis including all three EMQ subscales are reported in Supporting Information S1, Section 5.

3 | Results

In descriptive terms, infants spent on average 20.90% (SD = 13.12) of engaged looking time looking at the objects. The majority of infants' looking was therefore toward the "mid" area of the scene, encompassing the actor and the center of the chute. This is unsurprising, given that a dynamic action of a live person occupied this area, and that these are older 12-month-old infants likely to investigate multiple elements of a scene. The size of the model estimates reported below should be interpreted in this light.

The main results are reported in Table 1. The statistical model's fit to the data was better than that of a model with random effects only, χ^2 (7) = 28.74, p = 0.0002. The non-significant model intercept suggests no overall preference for either the congruent or incongruent object (β = −1.30, SE = 0.94, p = 0.18). There was a main effect of adult grip type (β = 7.86, SE = 1.76, $p < 0.001$), indicating that infants' relative preference for looking at the congruent versus the incongruent object was greater when the adult displayed the precision grip. There was no main effect of infant hand posture (p = 0.622; congruent preference in hands free condition: −1.70%, SD = 13.56, range −37.32 to 39.02; and in hands constrained condition: −0.77%, SD = 10.53, range −27.16 to 27.67).

There was a significant two-way interaction between infant hand posture and the EMQ fine motor score ($\beta = -4.02$, SE = 1.65, $p = 0.017$), as shown in Table 1. This indicates a statistical relation between infants' parent-reported fine motor skills, and infants' change in their relative preference for looking at the congruent versus the incongruent object in the hands constrained condition. Infants with higher fine motor scores showed a greater reduction in preference for the congruent object during the posture manipulation that constrained their hand-grip movement. There was also a three-way interaction between infant hand posture, EMQ fine motor score, and adult grip type, indicating that this effect was particularly pronounced for trials in which the adult displayed the precision grip type ($\beta = -7.19$, SE = 3.30, $p = 0.032$). This interaction is depicted in Figure 3 in the difference between the upper and lower right-hand quadrants (Figure 3B,D).

We also examined whether the infants may have spent less time looking at the overall scene in the hands constrained condition if the presence of the tape or mittens distracted them. Using overall raw looking times (in s), we conducted a *t*-test to compare the hands constrained and hands free conditions on infants' engaged looking time. There was no effect of infant hand posture on engaged looking time, (t (47) = 0.699, $p = 0.488$). Infants spent a mean of 2.94 s (SD = 0.54 s) engaged with the scene in each hands free trial, and 3.00 s (SD = 0.58 s) in each hands constrained trial, suggesting that they were not more distracted when wearing the tape and mittens.

4 | Discussion

Historically, a link between manual action perception and production in infants has been shown by using one of two methods: (a) relating infant motor skills to their processing of other people's reaching and grasping actions (e.g., Daum et al. 2011; Loucks and Sommerville 2012), or (b) by providing infants with new motor experiences and then examining effects on action perception (e.g., Sommerville et al. 2005). In this study, we took an alternative approach.

TABLE 1 | Model estimates of predictors for infant looking behavior.

Variable	Estimate	SE	*p*-value
Infant hand posture	0.781	1.578	0.622
Adult grip type	**7.858**	**1.756**	**< 0.001**
EMQ fine motor *z* score	1.125	0.974	0.254
Infant hand posture × adult grip type	0.865	3.153	0.785
Infant hand posture × EMQ fine motor	**−4.015**	**1.650**	**0.017**
Adult grip type × EMQ fine motor	−1.058	1.820	0.564
Infant hand posture × adult grip type × EMQ fine motor	**−7.190**	**3.297**	**0.032**
Intercept	−1.304	0.943	0.175

Note: Bold type indicates significant beta estimates.
Abbreviation: SE, standard error.

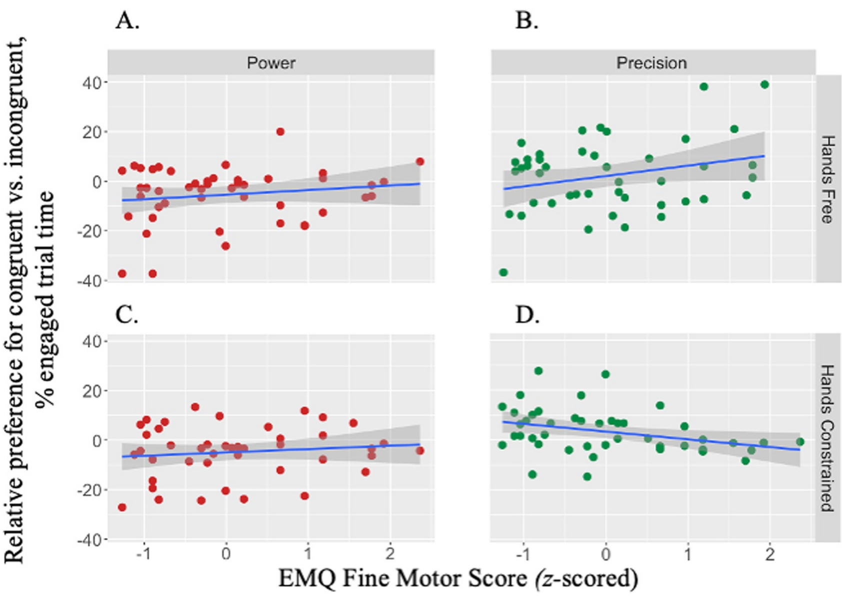

FIGURE 3 | Relations between EMQ fine motor score and looking behavior. Scatter plots with linear trend lines illustrating the effect of fine motor score on the difference in relative preference for the congruent versus incongruent object, by adult grip type and infant hand posture condition. Shaded area indicates SE.

We used a within-subjects experimental manipulation of hand posture to explore whether *inhibiting* infants' ability to match their hand posture to an actor's would alter their action perception. This own-posture manipulation influenced 12-month-old infants' perceptual processing of others' actions. Crucially, the effect of the hand constraint manipulation differed based on infants' "priors." That is, infants with better fine motor ability, and by extension those with increased or better quality self-experience of producing manual actions, were more affected by the experimental manipulation. We interpret these results to indicate, potentially, that a combination of prior self-experience and real-time motor interference during the experiment can play a role in how infants understand the perceived actions of others.

The main question posed by this work was whether the experimentally-assigned hand posture manipulation would affect infants' looking to the goal of an action based on its congruence with the experimenter's hand shape. Our initial hypothesis, based on work with adults (Ambrosini et al. 2012; Craighero and Zorzi 2012), was that putting the infant's hands in a posture that blocked any re-enactment of precision grips (and other forms of thumb-opposite grasping) would interfere with their access to motor representations of similar actions (referred to as "motor interference"). We did not find this as a main effect. Prior research suggested that infants with better motor skills, particularly fine motor skills, may be better able to determine which of two possible targets an adult was reaching for based on the adult's type of grip (e.g., Daum et al. 2011, in a paradigm with hands free conditions only). We did not find such an effect in our dataset.

We did find, however, that the change in infants' relative preference for the congruent versus the incongruent object under the hand constraint differed depending on their fine motor ability. Specifically, the higher infants scored on a parent-report motor ability questionnaire, the greater the reduction in their preference for the congruent object under the hand posture constraint. The three-way interaction between infant hand posture, adult grip type, and fine motor score indicates that the above-described effect was more pronounced in trials in which the actor used a more advanced grip type, specifically a precision grip. The better the infant's own fine motor skills, the more impacted they were when motor processes were inhibited—particularly for the action in which the adult grip type required more fine motor skill.

On a theoretical level, these results present a challenge both to views that action perception relies solely on production, and views that production has no effect. One way to account for the results is that they highlight the role of motor models and of embodied processes in infant action perception. The objective of using experimentally-induced motor interference was to examine the role of motor processes independent of infants' self-experience (in which prior visual, conceptual, and statistical processes can play a role). However, the effect of posture manipulation on relative preference for the congruent object varied as a function of infants' own fine motor skills. Although active motor processes may play a role during infant action perception, this may not be independent of individual differences in motor ability, and the visual, conceptual, and statistical information picked up through such prior motor experience. Thus, the pattern of findings obtained are not easily explained by accounts of the infant perception-production link that are singularly limited to, or which wholly reject, the role of concomitant motor processes.

The results suggest that multiple factors, not only motor experience, need to be considered. For example, infant looking preferences can differ based on task-related factors, including novelty, familiarity, and complexity of the task (e.g., Hunter and Ames 1988). The absence of an overall congruent object preference may have been the result of opposing looking preferences for the power versus precision grip trials. Using the Hunter and Ames model, one might speculate that the power grips (which appear earlier in infants' repertoires than precision grips) may be highly familiar to infants at 12 months. This may have led to a "novelty" preference during the power grip trials (i.e., an interest in the incongruent object), and to a "familiarity" preference during precision grip trials (an interest in the congruent object, as the infants were working to process the event). This posthoc speculation was not originally anticipated, and thus requires further research to investigate. We raise it to illustrate the value of remaining open, at a theoretical level, to the role of multiple factors.

4.1 | Relations to Existing Work

The present findings are consistent with an account of infant action perception that proposes motor processing as one component involved in infants' perception and interpretation of other people's actions. However, there are some nuances, both in the empirical approach and in the pattern of results, that need to be borne in mind. One difference in our results relative to existing work is that we did not find an overall significant preference for either the congruent or incongruent object as a main effect. This differs from previous work in which it was reported that infants as young as 6 months of age made anticipatory looks to an object congruent with the shape of a reaching hand (Ambrosini et al. 2013) and looked longer to a static action outcome incongruent with the reaching hand's original power or precision grasping shape (Daum et al. 2009; Daum et al. 2011). Given the dynamic nature of the action in the current study, and that the key stimulus was a reaching action (rather than a grasping outcome), we expected infants to exhibit a congruent object preference, that is, to spend more time looking at the object upon which they expected the action to conclude. Different methodologies may lead to different looking patterns.

A more substantial divergence from prior work was the type of empirical approach taken. An experimental manipulation of infants' own hand posture was used to interfere with the use of motor representations during the action observation event. This allows us to advance our understanding beyond extant research in at least two ways. First, in previous research, motor skill assessments and reports of prior experience have been used as proxy measures of motor processes during action perception, based on the assumption that infants with less experience will have weaker or absent motor representations of those specific actions (Colomer et al. 2023; Gerson et al. 2015; van Elk et al. 2008). Second, much of the existing work relating action perception and production has hinged on between-subjects comparisons of infants who do or do not exhibit specific motor skills, or has examined the effects of training in new skills (see Ní Choisdealbha and Meltzoff 2025, for a review). We approached the question from the opposite direction. Instead of asking whether motor experience—which could be naturally acquired, or induced through experimentally-assigned training—affects action perception, we tested infants who already had certain motor skills and used an experimental manipulation to investigate whether *interfering* with their concurrent access to motor representations affects their action perception.

While our interference method took a different approach than prior infant work, there are points of convergence in the results, which are of interest for theory. For example, although we did not find a main effect of the hand posture manipulation, we did find that the effect of hand posture manipulation on 12-month-old infants' looking behavior differed by their fine motor ability, and was more pronounced for infants with better fine motor abilities. This pattern of findings aligns well with previous work reporting that infants' ability to perform a precision or thumb-opposite grip alters action perception (Ambrosini et al. 2013; Daum et al. 2011; Loucks and Sommerville 2012). Indeed, the fact that hand posture manipulation had a more pronounced effect on infants with better fine motor ability, and on trials in which the perceived action involved fine motor skill, suggests that the hand posture manipulation paradigm disrupted infants' ability to use existing motor representations to parse an ongoing action. Infants with less developed fine motor representations may not have been affected as much by the motor interference because they were less inclined to use those representations to resolve the task.

4.2 | Limitations and Future Research

We acknowledge several limitations in this work. This first is that the restriction of the infants' hands may have caused changes in their looking behavior independent of the hypothesized motor interference. We did not find evidence that infants were more distracted in the hands constrained trials, because their engaged looking time was nearly identical in each condition; 2.96 s in hands free versus 3.00 s in hands constrained. In future work, the introduction of experimentally designed control conditions is possible, e.g. by using "control taping" which does not affect grasping, or by examining the effects of motor interference of one part of the body on looking to actions using other parts (e.g., kicking).

A second limitation is task complexity, given the dynamic scene shown to the infant by a live actor. In the current paradigm, there were two potential target objects, and their congruence was determined in relation to a third stimulus—the grip type displayed by the experimenter. Moreover, to reduce predictability, the experimenter's target changed from the large to the small object from trial to trial, and from cube to sphere every four trials. Further complexity was introduced by the two different adult grip types, power and precision grips, were each displayed by the same experimenter on different trials according to the counterbalancing schedule. The variation of the multi-trial procedure and resultant complexity may have increased cognitive demand.

Third, and related to the above, the main effect of adult grip type could reflect a general visual preference for the small object. Preference for the congruent object relative to the incongruent one was greater in precision grip trials, with infants spending 2.77% more engaged looking time looking at the congruent object in this case, and 5.16% less engaged looking time looking at it in the power grip trials. The main effect of adult grip type could therefore be interpreted as a visual preference for the small object, rather than a preference for the congruent object in precision grip trials specifically. Given the within-subjects, counterbalanced approach, this does not affect the overall finding that for infants with better fine motor ability, motor interference affected their relative preference for the congruent object—regardless of congruent object size. Whether object size or the actor's hand shape drove the main effect of grip type, the three-way interaction between infant fine motor skill, adult grip type, and infant hand posture indicates that infants with better fine motor skill (who are therefore more likely to be good precision graspers) were affected in accessing a representation of grasping the small object under motor interference.

There are a number of reasons why a small object may have attracted attention, including its novelty. Infants at 12 months may be less frequently exposed to small physical toys like the spheres and cubes used here, due to the potential choking hazard. Unfortunately, it is not possible to include object size in the statistical model to control for such a preference, because it is confounded with adult grip type (i.e., there were no precision grip trials in which the large object was congruent with the experimenter's hand). Future investigations using this motor interference paradigm might profitably employ stimuli similar to those used in previous reaching studies (Daum et al. 2009; Daum et al. 2011; Loucks and Sommerville 2012), i.e., identical objects (e.g., a cup) in one orientation which affords a precision grip (handle oriented toward actor's hand) and another which affords a power grip (cup barrel oriented toward actor's hand). This might remove differential looking behavior based purely on the size of the object without reference to the adult grip type.

In the future, our motor interference approach could be used to complement other infant action perception methodologies. It could be used in conjunction with habituation paradigms to explore how motor interference affects infants' detection of changes in others' actions and goals, or with neuroscience techniques (EEG/MEG/fNIRS) to test whether hand constraint affects motor activation during action observation. Finally, the infant motor interference approach could be used to complement active training techniques (e.g., sticky mittens) to examine whether sensorimotor processes mediate the effect of motor experience on object exploration and action perception (see Liu and Almeida 2023; Needham 2021; Ní Choisdealbha and Meltzoff 2025; van den Berg and Gredebäck 2021 for further discussion).

5 | Conclusions

The current work offers an infant-friendly motor interference method for studying the potential contribution of motor processes to infants' processing and interpretation of other people's actions. We found that for infants with better fine motor skills, experimentally manipulating their hand posture so they could not perform a thumb-opposite grip influenced their looking behavior toward adults' reaching and grasping actions, particularly when these involved precision grips. It is reasonable that infants with better fine motor skills would be particularly affected by the experimental treatment (restricting their ability to enact a thumb-opposite or precision grip), because such infants likely have an existing motor representation of this specific action that they could recruit, or be inhibited from recruiting, when observing others' actions. This posture manipulation paradigm—a manipulation that can be effectively used with young infants—has potential for future use in examining how infants engage motor processes during action perception.

Author Contributions

Áine Ní Choisdealbha: conceptualization, funding acquisition, investigation, methodology, formal analysis, writing – original draft, writing – review and editing. **Andrew N. Meltzoff:** conceptualization, funding acquisition, methodology, writing – review and editing, resources, supervision.

Acknowledgments

This project received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 101027836 (ANC), as well as the Bezos Family Foundation (ANM). We are grateful to the families who took part in the research. We thank Dr. Rechele Brooks for statistical advice, technical assistance, and feedback on an earlier version of this paper; Grace Mak for research assistance; Dawn Hathaway for administrative assistance; and Maria Madero, Lucy Nowicki, and Mai Nguyen for lab assistance.

Ethics Statement

The research was approved by the Institutional Review Board at the University of Washington. The research was conducted in line with the Declaration of Helsinki and the ethical standards of the American Psychological Association.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in OSF at https://osf.io/mz3xk/, reference number DOI 10.17605/OSF.IO/MZ3XK.

References

Ambrosini, E., V. Reddy, A. de Looper, M. Costantini, B. Lopez, and C. Sinigaglia. 2013. "Looking Ahead: Anticipatory Gaze and Motor Ability in Infancy." *PLoS One* 8, no. 7: e67916. https://doi.org/10.1371/journal.pone.0067916.

Ambrosini, E., C. Sinigaglia, and M. Costantini. 2012. "Tie My Hands, Tie My Eyes." *Journal of Experimental Psychology: Human Perception and Performance* 38, no. 2: 263–266. https://doi.org/10.1037/a0026570.

Avenanti, A., M. Candidi, and C. Urgesi. 2013. "Vicarious Motor Activation During Action Perception: Beyond Correlational Evidence." *Frontiers in Human Neuroscience* 7: 185. https://doi.org/10.3389/fnhum.2013.00185.

Bakker, M., M. M. Daum, A. Handl, and G. Gredebäck. 2015. "Neural Correlates of Action Perception at the Onset of Functional Grasping." *Social Cognitive and Affective Neuroscience* 10, no. 6: 769–776. https://doi.org/10.1093/scan/nsu119.

Bakker, M., J. A. Sommerville, and G. Gredebäck. 2016. "Enhanced Neural Processing of Goal-Directed Actions After Active Training in 4-Month-Old Infants." *Journal of Cognitive Neuroscience* 28, no. 3: 472–482. https://doi.org/10.1162/jocn_a_00909.

Barragan, R. C., R. Brooks, and A. N. Meltzoff. 2020. "Altruistic Food Sharing Behavior by Human Infants After a Hunger Manipulation." *Scientific Reports* 10: 1785. https://doi.org/10.1038/s41598-020-58645-9.

Begum Ali, J., C. Spence, and A. J. Bremner. 2015. "Human Infants' Ability to Perceive Touch in External Space Develops Postnatally." *Current Biology* 25, no. 20: R978–R979. https://doi.org/10.1016/j.cub.2015.08.055.

Bertenthal, B. I., and T. W. Boyer. 2025. "Human Infants' Perception and Understanding of Others' Actions." *Infant Behavior and Development* 80: 102098. https://doi.org/10.1016/j.infbeh.2025.102098.

Bremner, A. J., D. Mareschal, S. Lloyd-Fox, and C. Spence. 2008. "Spatial Localization of Touch in the First Year of Life: Early Influence of a Visual Spatial Code and the Development of Remapping Across Changes in Limb Position." *Journal of Experimental Psychology: General* 137, no. 1: 149–162. https://doi.org/10.1037/0096-3445.137.1.149.

Butterworth, G., E. Verweij, and B. Hopkins. 1997. "The Development of Prehension in Infants: Halverson Revisited." *British Journal of Developmental Psychology* 15, no. 2: 223–236. https://doi.org/10.1111/j.2044-835X.1997.tb00736.x.

Cannon, E. N., and A. L. Woodward. 2008. "Action Anticipation and Interference: A Test of Prospective Gaze." *Proceedings of the Annual Meeting of the Cognitive Science Society* 30: 981–985. https://escholarship.org/uc/item/8wt4n6wf.

Cannon, E. N., A. L. Woodward, G. Gredebäck, C. von Hofsten, and C. Turek. 2012. "Action Production Influences 12-Month-Old Infants' Attention to Others' Actions." *Developmental Science* 15, no. 1: 35–42. https://doi.org/10.1111/j.1467-7687.2011.01095.x.

Chung, H., M. Meyer, R. Debnath, N. A. Fox, and A. Woodward. 2022. "Neural Correlates of Familiar and Unfamiliar Action in Infancy." *Journal of Experimental Child Psychology* 220: 105415. https://doi.org/10.1016/j.jecp.2022.105415.

Colomer, M., H. Chung, M. Meyer, et al. 2023. "Action Experience in Infancy Predicts visual-Motor Functional Connectivity During Action Anticipation." *Developmental Science* 26, no. 3: e13339. https://doi.org/10.1111/desc.13339.

Craighero, L., and V. Zorzi. 2012. "Hand–Foot Motor Priming in the Presence of Temporary Inability to Use Hands." *Visual Cognition* 20, no. 1: 77–93. https://doi.org/10.1080/13506285.2011.639315.

Daum, M. M., W. Prinz, and G. Aschersleben. 2011. "Perception and Production of Object-Related Grasping in 6-Month-Olds." *Journal of Experimental Child Psychology* 108, no. 4: 810–818. https://doi.org/10.1016/j.jecp.2010.10.003.

Daum, M. M., M. T. Vuori, W. Prinz, and G. Aschersleben. 2009. "Inferring the Size of a Goal Object From an Actor's Grasping Movement in 6- and 9-Month-Old Infants." *Developmental Science* 12, no. 6: 854–862. https://doi.org/10.1111/j.1467-7687.2009.00831.x.

de Klerk, C. C. J. M., M. H. Johnson, and V. Southgate. 2015. "An EEG Study on the Somatotopic Organisation of Sensorimotor Cortex Activation During Action Execution and Observation in Infancy." *Developmental Cognitive Neuroscience* 15: 1–10. https://doi.org/10.1016/j.dcn.2015.08.004.

de Klerk, C. C. J. M., V. Southgate, and G. Csibra. 2016. "Predictive Action Tracking Without Motor Experience in 8-Month-Old Infants." *Brain and Cognition* 109: 131–139. https://doi.org/10.1016/j.bandc.2016.09.010.

de Lange, F. P., R. C. Helmich, and I. Toni. 2006. "Posture Influences Motor Imagery: An fMRI Study." *NeuroImage* 33, no. 2: 609–617. https://doi.org/10.1016/j.neuroimage.2006.07.017.

Falck-Ytter, T., G. Gredebäck, and C. von Hofsten. 2006. "Infants Predict Other People's Action Goals." *Nature Neuroscience* 9, no. 7: 878–879. https://doi.org/10.1038/nn1729.

Faul, F., E. Erdfelder, A.-G. Lang, and A. Buchner. 2007. "G*Power 3: A Flexible Statistical Power Analysis Program for the Social, Behavioral, and Biomedical Sciences." *Behavior Research Methods* 39, no. 2: 175–191. https://doi.org/10.3758/BF03193146.

Filippi, C. A., and A. L. Woodward. 2016. "Action Experience Changes Attention to Kinematic Cues." *Frontiers in Psychology* 7: 19. https://doi.org/10.3389/fpsyg.2016.00019.

Gerson, S. A., H. Bekkering, and S. Hunnius. 2015. "Short-Term Motor Training, But Not Observational Training, Alters Neurocognitive Mechanisms of Action Processing in Infancy." *Journal of Cognitive Neuroscience* 27, no. 6: 1207–1214. https://doi.org/10.1162/jocn_a_00774.

Halverson, H. M. 1931. "An Experimental Study of Prehension in Infants by Means of Systematic Cinema Records." *Genetic Psychology Monographs* 10: 107–286.

Hunnius, S., and H. Bekkering. 2010. "The Early Development of Object Knowledge: A Study of Infants' Visual Anticipations During Action Observation." *Developmental Psychology* 46, no. 2: 446–454. https://doi.org/10.1037/a0016543.

Hunnius, S., and H. Bekkering. 2014. "What Are You Doing? How Active and Observational Experience Shape Infants' Action Understanding." *Philosophical Transactions of the Royal Society B: Biological Sciences* 369, no. 1644: 20130490. https://doi.org/10.1098/rstb.2013.0490.

Hunter, M. A., and E. W. Ames. 1988. "A Multifactor Model of Infant Preferences for Novel and Familiar Stimuli." In *Advances in Infancy Research*, edited by C. Rovee-Collier and L. P. Lipsitt, 5: 69–95. Ablex Publishing.

Ionta, S., and O. Blanke. 2009. "Differential Influence of Hands Posture on Mental Rotation of Hands and Feet in Left and Right Handers." *Experimental Brain Research* 195, no. 2: 207–217. https://doi.org/10.1007/s00221-009-1770-0.

Ionta, S., A. D. Fourkas, M. Fiorio, and S. M. Aglioti. 2007. "The Influence of Hands Posture on Mental Rotation of Hands and Feet." *Experimental Brain Research* 183, no. 1: 1–7. https://doi.org/10.1007/s00221-007-1020-2.

Jacquet, P. O., and A. Avenanti. 2015. "Perturbing the Action Observation Network During Perception and Categorization of Actions' Goals and Grips: State-Dependency and Virtual Lesion TMS Effects." *Cerebral Cortex* 25, no. 3: 598–608. https://doi.org/10.1093/cercor/bht242.

Kuznetsova, A., P. B. Brockhoff, and R. H. B. Christensen. 2017. "lmerTest Package: Tests in Linear Mixed Effects Models." *Journal of Statistical Software* 82, no. 13: 1–26. https://doi.org/10.18637/jss.v082.i13.

Libertus, K., and R. J. Landa. 2013. "The Early Motor Questionnaire (EMQ): A Parental Report Measure of Early Motor Development." *Infant Behavior and Development* 36, no. 4: 833–842. https://doi.org/10.1016/j.infbeh.2013.09.007.

Liu, S., and M. Almeida. 2023. "Knowing Before Doing: Review and Mega-Analysis of Action Understanding in Prereaching Infants." *Psychological Bulletin* 149, no. 5–6: 294–310. https://doi.org/10.1037/bul0000393.

Loucks, J., and J. A. Sommerville. 2012. "The Role of Motor Experience in Understanding Action Function: The Case of the Precision Grasp." *Child Development* 83, no. 3: 801–809. https://doi.org/10.1111/j.1467-8624.2012.01735.x.

Marshall, P. J., and A. N. Meltzoff. 2014. "Neural Mirroring Mechanisms and Imitation in Human Infants." *Philosophical Transactions of the Royal Society B: Biological Sciences* 369, no. 1644: 20130620. https://doi.org/10.1098/rstb.2013.0620.

Marshall, P. J., T. Young, and A. N. Meltzoff. 2011. "Neural Correlates of Action Observation and Execution in 14-Month-Old Infants: An Event-Related EEG Desynchronization Study." *Developmental Science* 14, no. 3: 474–480. https://doi.org/10.1111/j.1467-7687.2010.00991.x.

Meltzoff, A. N. 2007. "The 'Like Me' Framework for Recognizing and Becoming an Intentional Agent." *Acta Psychologica* 124, no. 1: 26–43. https://doi.org/10.1016/j.actpsy.2006.09.005.

Meltzoff, A. N. 2013. "Origins of Social Cognition: Bidirectional Self-Other Mapping and the "Like-Me" Hypothesis." In *Navigating the Social World: What Infants, Children, and Other Species Can Teach Us*, edited by M. R. Banaji and S. A. Gelman, 139–144. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199890712.003.0025.

Meltzoff, A. N., and R. Brooks. 2008. "Self-Experience as a Mechanism for Learning About Others: A Training Study in Social Cognition." *Developmental Psychology* 44, no. 5: 1257–1265. https://doi.org/10.1037/a0012888.

Melzer, A., W. Prinz, and M. M. Daum. 2012. "Production and Perception of Contralateral Reaching: A Close Link by 12 Months of Age." *Infant Behavior and Development* 35, no. 3: 570–579. https://doi.org/10.1016/j.infbeh.2012.05.003.

Meyer, M., R. Braukmann, J. C. Stapel, H. Bekkering, and S. Hunnius. 2016. "Monitoring Others' Errors: The Role of the Motor System in Early Childhood and Adulthood." *British Journal of Developmental Psychology* 34, no. 1: 66–85. https://doi.org/10.1111/bjdp.12101.

Monroy, C. D., M. Meyer, L. Schröer, S. A. Gerson, and S. Hunnius. 2019. "The Infant Motor System Predicts Actions Based on Visual Statistical Learning." *NeuroImage* 185: 947–954. https://doi.org/10.1016/j.neuroimage.2017.12.016.

Needham, A. W. 2021. "Learning From Sticky Mittens: Commentary on van den Berg and Gredebäck (2020)." *Developmental Science* 24, no. 4: e13083. https://doi.org/10.1111/desc.13083.

Newell, K. M., D. M. Scully, P. V. McDonald, and R. Baillargeon. 1989. "Task Constraints and Infant Grip Configurations." *Developmental Psychobiology* 22, no. 8: 817–831. https://doi.org/10.1002/dev.420220806.

Ní Choisdealbha, Á., N. Brady, and C. Maguinness. 2011. "Differing Roles for the Dominant and Non-Dominant Hands in the Hand Laterality Task." *Experimental Brain Research* 211, no. 1: 73–85. https://doi.org/10.1007/s00221-011-2652-9.

Ní Choisdealbha, Á., and A. N. Meltzoff. 2025. "Advances in Understanding the Perception-Production Link: Evidence From Infant Eye, Brain, and Motor Behavior." *Infant Behavior and Development* 80. https://doi.org/10.1016/j.infbeh.2025.102100.

Ní Choisdealbha, Á., and V. Reid. 2014. "The Developmental Cognitive Neuroscience of Action: Semantics, Motor Resonance and Social Processing." *Experimental Brain Research* 232, no. 6: 1585–1597. https://doi.org/10.1007/s00221-014-3924-y.

Ní Choisdealbha, Á., G. Westermann, and V. Reid. 2025. "Neural Representations of Grasp Congruence During the Emergence of Precision Grasping." *Infancy* 30, no. 3: e70026. https://doi.org/10.1111/infa.70026.

Nyström, P. 2008. "The Infant Mirror Neuron System Studied With High Density EEG." *Social Neuroscience* 3, no. 3–4: 334–347. https://doi.org/10.1080/17470910701563665.

Nyström, P., T. Ljunghammar, K. Rosander, and C. von Hofsten. 2011. "Using Mu Rhythm Desynchronization to Measure Mirror Neuron Activity in Infants." *Developmental Science* 14, no. 2: 327–335. https://doi.org/10.1111/j.1467-7687.2010.00979.x.

Rigato, S., J. Begum Ali, J. van Velzen, and A. J. Bremner. 2014. "The Neural Basis of Somatosensory Remapping Develops in Human Infancy." *Current Biology* 24, no. 11: 1222–1226. https://doi.org/10.1016/j.cub.2014.04.004.

Saby, J. N., A. N. Meltzoff, and P. J. Marshall. 2013. "Infants' Somatotopic Neural Responses to Seeing Human Actions: I've Got You Under My Skin." *PLoS One* 8, no. 10: e77905. https://doi.org/10.1371/journal.pone.0077905.

Schwarzer, G., and B. Jovanovic. 2024. "Infants' Predictive Minds: The Role of Motor Experience." *Child Development Perspectives* 18, no. 3: 123–128. https://doi.org/10.1111/cdep.12506.

Sekiyama, K., T. Kinoshita, and T. Soshi. 2014. "Strong Biomechanical Constraints on Young Children's Mental Imagery of Hands." *Royal Society Open Science* 1, no. 4: 140118. https://doi.org/10.1098/rsos.140118.

Skerry, A. E., S. E. Carey, and E. S. Spelke. 2013. "First-Person Action Experience Reveals Sensitivity to Action Efficiency in Prereaching Infants." *Proceedings of the National Academy of Sciences* 110, no. 46: 18728–18733. https://doi.org/10.1073/pnas.1312322110.

Smith, D. K., and K. Libertus. 2022. "The Early Motor Questionnaire Revisited: Starting Points, Standardized Scores, and Stability." *Journal of Experimental Child Psychology* 223: 105492. https://doi.org/10.1016/j.jecp.2022.105492.

Sommerville, J. A., and A. L. Woodward. 2005. "Pulling Out the Intentional Structure of Action: The Relation Between Action Processing and Action Production in Infancy." *Cognition* 95, no. 1: 1–30. https://doi.org/10.1016/j.cognition.2003.12.004.

Sommerville, J. A., A. L. Woodward, and A. Needham. 2005. "Action Experience Alters 3-Month-Old Infants' Perception of Others' Actions." *Cognition* 96, no. 1: B1–B11. https://doi.org/10.1016/j.cognition.2004.07.004.

Southgate, V., and K. Begus. 2013. "Motor Activation During the Prediction of Nonexecutable Actions in Infants." *Psychological Science* 24, no. 6: 828–835. https://doi.org/10.1177/0956797612459766.

Southgate, V., M. H. Johnson, and G. Csibra. 2008. "Infants Attribute Goals Even to Biomechanically Impossible Actions." *Cognition* 107, no. 3: 1059–1069. https://doi.org/10.1016/j.cognition.2007.10.002.

Southgate, V., M. H. Johnson, I. El Karoui, and G. Csibra. 2010. "Motor System Activation Reveals Infants' On-Line Prediction of Others' Goals." *Psychological Science* 21, no. 3: 355–359. https://doi.org/10.1177/0956797610362058.

Southgate, V., M. H. Johnson, T. Osborne, and G. Csibra. 2009. "Predictive Motor Activation During Action Observation in Human Infants." *Biology Letters* 5, no. 6: 769–772. https://doi.org/10.1098/rsbl.2009.0474.

Stapel, J. C., S. Hunnius, M. Meyer, and H. Bekkering. 2016. "Motor System Contribution to Action Prediction: Temporal Accuracy Depends on Motor Experience." *Cognition* 148: 71–78. https://doi.org/10.1016/j.cognition.2015.12.007.

Toussaint, L., C. Bidet-Ildei, C. Scotto, and A. Badets. 2023. "Effects of Short-Term Hand Immobilization on Anticipatory Mechanism for Tool Use." *Psychological Research* 87, no. 8: 2407–2418. https://doi.org/10.1007/s00426-023-01824-w.

Touwen, B. C. L. 1971. "A Study on the Development of Some Motor Phenomena in Infancy." *Developmental Medicine and Child Neurology* 13, no. 4: 435–446. https://doi.org/10.1111/j.1469-8749.1971.tb03050.x.

van den Berg, L., and G. Gredebäck. 2021. "The Sticky Mittens Paradigm: A Critical Appraisal of Current Results and Explanations." *Developmental Science* 24, no. 5: e13036. https://doi.org/10.1111/desc.13036.

van Elk, M., H. T. van Schie, S. Hunnius, C. Vesper, and H. Bekkering. 2008. "You'll Never Crawl Alone: Neurophysiological Evidence for Experience-Dependent Motor Resonance in Infancy." *NeuroImage* 43, no. 4: 808–814. https://doi.org/10.1016/j.neuroimage.2008.07.057.

Woo, B. M., S. Liu, and E. S. Spelke. 2024. "Infants Rationally Infer the Goals of Other People's Reaches in the Absence of first-person Experience With Reaching Actions." *Developmental Science* 27, no. 3: e13453. https://doi.org/10.1111/desc.13453.

Woodward, A. L. 1998. "Infants Selectively Encode the Goal Object of an Actor's Reach." *Cognition* 69, no. 1: 1–34. https://doi.org/10.1016/S0010-0277(98)00058-4.

Zimmermann, M., R. G. J. Meulenbroek, and F. P. de Lange. 2012. "Motor Planning is Facilitated by Adopting an Action's Goal Posture: An fMRI Study." *Cerebral Cortex* 22, no. 1: 122–131. https://doi.org/10.1093/cercor/bhr098.

Zimmermann, M., I. Toni, and F. P. de Lange. 2013. "Body Posture Modulates Action Perception." *Journal of Neuroscience* 33, no. 14: 5930–5938. https://doi.org/10.1523/JNEUROSCI.5570-12.2013.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Supporting Information S1: infa70071-sup-0001-suppl-data.docx.